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Newfoundland Shelf Sea Ice Program, 1991

S.J. Prinsenberg and I.K. Peterson

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ABSTRACT

Prinsenberg, S.J. and I.K. Peterson, 1992. Newfoundland Shelf Sea Ice Program, 1991. Can. Tech. Rep. Hydrogr. Ocean. Sci. No. 141:vii+99 p.

Nineteen ice beacons, deployed on the land-fast and mobile pack ice, collected atmospheric, ice and oceanographic data off the coast of Labrador and Newfoundland during the winter of 1990-1991. The data were telemetered via satellite and used to study variations in sea ice properties in response to atmospheric and oceanographic conditions. This manuscript presents the processed data and the preliminary analysis of the results for the 1991 winter survey.

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Dix-neuf balises des glaces ont été déployées sur la banquise côtière et la banquise pour la collecte de données atmosphériques, glacielles et océanographiques au large de la côte du Labrador et de Terre-Neuve pendant l'hiver de 1990-1991. Les données ont été transmises par télémétrie par satellite et utilisées pour l'étude de variations des propriétés de la glace de mer en réponse aux conditions atmosphériques et océanographiques. Ce rapport présente les données traitées et une analyse préliminaire des résultats pour le relevé de l'hiver 1991.

TABLE CAPTIONS

Table 1. Areas, start and end times in 1991 calendar days, types and sensors (x) for ice beacons on both land-fast and drifting ice. Area numbers are 1 for Cartwright, 2 for Hudson/Davis Straits and 3 for Labrador pack ice. The times represent the times when the beacons were transmitting; in some cases, the sensors did not work over the whole period.

Table 2. Accuracy and resolution of ice beacon data parameters.

Table 3. Observed and ice chart ice thicknesses for February and March, 1991. Sizes of floes on which beacons were deployed are listed.

Table 4. Air temperature anomalies at stations along the Canadian east coast from "Climatic Perspectives" published monthly by Atm. Env. Ser. (1991a).

Table 5. Monthly displacements of ice due to wind forcing. Monthly mean wind speeds for 16 directions were used, each an average over an 22.5° sector, multiplied by their frequency of occurrence and by 2.5% to convert to wind speed to ice speed and turned 35° to the right of the wind to represent ice drift direction.

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FIGURE CAPTIONS

Fig. 1. Ice chart of February 13, 1991, showing the positions and 2-day displacements of the beacons deployed on February 12.

Fig. 2. Ice chart of February 14, 1991, showing the positions and 2-day displacements of the beacons deployed on February 14.

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1.0 INTRODUCTION

Sea ice over the Northeast Newfoundland shelf and the Grand Banks poses a threat to safe operations at sea associated with hydrocarbon exploration, shipping and fishing. Several programs of the Department of Fisheries and Oceans address the seasonal variability of the movement and extent of the pack ice along the east coast of Canada. Advection of ice from farther north by wind and ocean currents is the major source of ice over the Northeast Newfoundland shelf. This ice is thicker and takes longer to decay than the thinner ice formed locally along the Labrador coast. The southern ice extent is determined by a balance between the volume of ice advected southwards and the volume melted due to oceanic and atmospheric heat fluxes.

During the 1990-91 ice season, 19 ice beacons were deployed on land-fast and mobile pack ice off the Labrador coast in order to monitor the atmospheric, ice and ocean conditions by the ice beacons moving southwards over the Newfoundland shelf. After a description of the field program and instrumentation, this manuscript presents the data obtained by the beacons, as well as CTD and ice thickness data collected from the floes the beacons were deployed on. Monthly ice extent, air temperature and wind anomalies for the 1990/91 ice season are also presented. The appendices show the data in greater detail.

2.0 INSTRUMENTATION

2.1 ICE BEACONS

Eight different types of ice beacons were deployed (Table 1), all telemetered their data via the Argos satellite system. Service Argos computes the position of each ice beacon from the measured Doppler shift of the beacon transmissions, which occur for about 10 minutes on about 10 passes per day. Of the nineteen ice beacons deployed, seventeen were designed and manufactured by Metocean Data Systems Ltd, and two by Hermes Electronics Ltd.

The beacons had a variety of sensor packages (Table 1) whose data along with the beacon's position were telemetered via Argos satellite. The accuracy and resolution of the sensors are listed in Table 2. Six beacons just collected position data. Of these six, four were air-dropped from the ice reconnaissance aircraft of Canadian Ice Centre on the offshore pack ice east and northeast of Hudson Strait. The other two beacons, manufactured by Hermes, were deployed by helicopter on the pack ice over the Labrador shelf. Three beacons, which were able to float in open water, not only reported position, but also hull temperature in order to help determine when the floes they were deployed on melted. Two beacons, Compact Meteorological Ice Beacons (CMIBs) reported barometric pressure, air temperature, and ice surface temperature.

Two beacons were equipped with anemometers made by R. M. Young Co., positioned at a height of 2 metres above the ice surface. These beacons were designed to average the wind speed and direction over 10 minutes once per hour, and transmit these 10 minute averages for each of the previous 6 hours along with the barometric pressure, air temperature and the time period the beacon has been operating.

Three types of ice beacons provided temperature profiles in air, ice and water. The first of these, Ice Monitoring Platforms (IMPs), measure air temperature and sub-surface temperatures at 28 locations 6.4 cm apart through the ice and water column (Peterson et al., 1991). It consists of a long staff containing both the transmitter and the thermistors. Its large battery pack enables it to operate in Arctic conditions for one year. A second version, deployed in the land-fast ice in Cartwright harbour, has 9 air/snow thermistors and 21 ice/water thermistors 10 cm apart. A third and smaller version of this beacon (SIMP), has a smaller battery pack which enabled it to operate for only up to 3 months in areas like the marginal ice zone. It measures barometric pressure, and has 8 air/snow thermistors 10 cm apart and 20 ice/water thermistors 5 cm apart. The ice staff, containing the thermistors, is connected to the transmitter by an electrical cable. Three beacons of this latter type were deployed in the winter of 1990/1991.

2.2 TEMPERATURE-SALINITY INSTRUMENTATION

Temperature and salinity profiles were collected through auger holes at ice beacon deployment sites when time and weather permitted the extra work. The salinity/temperature profiles were taken with a self-recording Seabird SBE-25 CTD probe. The CTD probe was lowered through augered ice holes by a cable fastened to a portable winch driven by the auger gasoline engine used also to drill the CTD ice holes. The accuracy/resolution of the sensors of the Seabird are .0004/.0003 $^{\circ}$C for temperature, .01/.005ppt for salinity and .25%/.015% of depth range for pressure.

Salinity samples of the ice were obtained from ice chips, collected at various depths of the ice cover, and stored and melted in standard sea water sample bottles. During the March trip, salinity values were determined in the field with an AO-10419 hand-held refractometer which could be read to $\pm$.5ppt. To check on the accuracy of refractometer-determined values for future work, salinity values of samples from the March and May field trips were determined by both the refractometer and a Guildline Autosalometer.

3.0 STUDY AREA AND FIELD PROGRAM

The field program deployed a total of 19 satellite-tracked ice beacons on the pack ice off the coast of Labrador in order to study the response of the ice to wind stress and ocean currents. A detailed field schedule is listed in Appendix A. For safety, two helicopters from Universal Helicopters Ltd., stationed out of Goose Bay, were used during the field trips. One helicopter carried eight ice beacons, while the second carried the augers and CTD system for the collection of temperature/salinity data of the water column at the deployment sites. Equipment for collecting ice salinity samples and ice thickness measurements was also transported in the second helicopter.

On January 9, three beacons were deployed by snowmobile for test trials on the land-fast ice in Cartwright harbour. The instruments were placed near the site where ice thickness and snow depth measurements are collected weekly each winter by a contractor for the Canadian Ice Centre. The beacons

consisted of an Ice Monitoring Platform (IMP) which monitors temperature profiles in air, ice and water, the new smaller version of the IMP called SIMP, and an anemometer beacon.

On February 2 and 3, four beacons were air-dropped on the pack ice east and northeast of Hudson Strait by the Canadian Ice Centre's ice reconnaissance aircraft, in order to provide ice drift information at this higher latitude.

On February 12, 1991, ice beacons were deployed off Cartwright (54°N) using two helicopters. The ice chart for February 13 (Fig. 1) showed the ice cover extending south as far as the Grand Banks and east past the 1000m isobath, the median position of the eastern ice edge. The chart indicated that the three beacons, deployed on February 12, were on pack ice with a $9^{+}/10$ concentration and a maximum thickness ranging from 70-120cm offshore to 15-30cm inshore (Table 3). A position-only ice beacon was deployed at the outer site, an Ice Monitoring Platform (IMP) at the middle site, and a Compact Meteorological Ice Beacon (CMIB) at the inner site.

After a snow storm on February 13, three additional ice beacons were deployed off Cartwright by helicopter on February 14 (Fig. 2) during very cold and windy conditions. A position-only beacon was deployed at the outer site, an anemometer beacon at the middle site, and a Small Ice Monitoring Platform (SIMP) at the inner site. Later in the day, the Cartwright harbour site was revisited to collect ice samples, ice thickness and snow depth measurements and to remove the anemometer beacon, which was malfunctioning.

The second set of six ice beacons was deployed by helicopter on March 15 and 16 (Fig. 3). A severe storm, with onshore winds lasting for several days, had reduced the pack ice to a narrow band of rafted ice rubble, compacted against the southern Labrador coast. The three beacons deployed on March 15 off Mary's Harbour south of Cartwright, were within an area on the ice chart having a maximum ice thickness of over 120cm and small (20-100m) ice floes. The beacons were deployed on floes 30-90m in diameter. Ice thicknesses were highest (184cm) at the middle site where a large seal herd was encountered. Position-only beacons were deployed at the outer and middle sites, and a SIMP was deployed at the inner site.

On March 16, three ice beacons were deployed north off Cartwright, where again the pack ice consisted mostly of thick, rubbled pack ice. The floes on which beacons were deployed were the largest in the area, with diameters of up to 2.0km, and appeared to have been formed later than the surrounding rubbled pack ice. A position-only ice beacon was deployed at the outer site, a Small Ice Monitoring Platform (SIMP) at the middle site, and a Compact Meteorological Ice Beacon (CMIB) at the inner site. Again, the Cartwright harbor site was revisited to collect ice samples and ice thickness and snow depth measurements.

On May 15, when the ice in Cartwright harbour was quickly melting, the the two ice beacons in the harbour were recovered, and ice and water samples were collected.

4.0 PRELIMINARY RESULTS

4.1 1990/1991 ICE COVER ANOMALY

During the winter of 1990/91, the Canadian east coast experienced below-normal air temperatures (Table 4) and above-normal ice extent. During the ice cover advance along the Labrador coast in 1991 (January to March), air temperatures were 2.5 $^{\circ}$C below normal, increasing the ice growth throughout the area and decreasing the ice melt rates along the advancing ice edge. This was stated in the January 14-20 Climatic Perspectives, published by Environment Canada: the "Persistent cold weather accelerated ice extent on East Coast" and the ice cover "extent was considered 2 to 3 weeks ahead of normal". When the ice cover retreated from April to June, air temperatures in the southern region remained 1.8 $^{\circ}$C below normal, reducing ice melt rates.

Climatological wind-driven ice drift

Cold Arctic air causes ice growth along the Labrador and Newfoundland coasts and advects the pack ice down from higher latitudes. Monthly surface wind histograms can be used to estimate monthly ice displacements assuming free-drift at 2.5% of the wind speed and 35 $^{\circ}$ to the right of the wind

(Peterson and Prinsenberg, 1989). For 25-year mean winds (1955-1980), the distances the ice drifted per month due to wind forcing in 16 directions (22.5° sections) are shown in Figure 4. For each month, the figure shows the contour made by joining the 16 vector end points. These 16 displacement vectors can be vectorially added to provide a net displacement per month (Table 4) and show that for the Newfoundland shelf, ice advected at 145 km/month by the wind towards the southeast in winter (Jan-Mar) and at 90km/month towards the south-southeast in the spring (Apr-Jun). For the southern Labrador coast, the ice advected at 170 km/month to the southeast in winter. For this case, the direction appears to be bimodal; to the northeast (offshore) and to the south (along-shore). In the spring, the ice advected primarily to the south but at a reduced rate of 100km/month.

For the 1990/91 ice season, winds and inferred ice displacements (Fig. 4), were higher than the 1955-80 means (Table 5) by 37% for the winter off Newfoundland, and 55 and 90% for the winter and spring periods off southern Labrador. In general, ice drifted in 1990/91 20° clockwise from the 25-year mean, reducing the offshore ice transport and thus ice was more likely to remain on the shelf (Fig. 4). This was especially noticeable for March (Table 5), when the ice drift direction rotated from a mean of 140° and 150° to 210° and 190° for the Newfoundland and southern Labrador regions, respectively. During this period, a storm with onshore wind components rafted the pack ice against the Newfoundland coast.

The ice cover in 1990/91 approached the maximum southern extent reached over the last 28 years (Figs. 5 and 6). The December ice coverage in the Hamilton Bank region was doubled, as was the January ice extent in the NE Newfoundland shelf region (Fig. 7). The February 11-17 Climatic Perspectives stated: "Compared to records dating back to 1958, the extensive pack ice along Canada's east coast extended as far south as the maximum limit ever observed for this date. This was mainly due to the colder than normal air temperatures that have prevailed since the beginning of the year". Throughout the winter, the areal extent of the ice cover was above normal in all areas except for a short period in March (Figs.6b and 7) when a storm with a persistent onshore wind component pushed the pack ice inshore causing severe rafting. The ice cover over the NE Newfoundland shelf area was reduced in width from 100 miles

to 30 miles, suggesting rafting up to three layers on the average, increasing the inshore ice cover thickness from an average of 60cm to 180cm. Shipping in and out of coastal ports of Newfoundland became extremely difficult. As stated in the March 11-17 Climatic Perspectives: "Another storm battered the Maritimes, producing heavy snowfalls and strong winds. Persistent (onshore) winds over the ice covered waters jammed the ice pack against the Cape Breton shoreline and the northeast coast of Newfoundland, effectively impeding ship and ferry traffic trying to get in and out of some harbours."

With the southern pack ice rafted along the coast, the edge of the thick (> 1m) ice could move southwards unabated from its location in the Hamilton Bank region, bringing with it the annual flux of ice bergs. The ice cover retreated slowly, with ice in all three areas lasting as long as the 25 year observed maximum (Fig. 7). Ice lingered around the southern Grand Banks until early May, over the NE Newfoundland shelf until mid July and in the Hamilton Bank area until early August. As stated in the June 10-16 Climatic Perspectives: "Newfoundland was plagued by Arctic sea ice" and "Ice conditions along the north coast of the island were the worst they have been in 25 years, as Arctic ice continued to drift southwards along the Labrador coast." With the extended ice season and general cool and wet conditions for the months of May and June, people in Newfoundland were wondering by mid April "When will summer come to Newfoundland?" (July 8-14 Climatic Perspectives).

4.2 ICE BEACON TRAJECTORIES

The start and end times over which the ice beacons operated were shown in Table 1. The operating period on the ice ranged from less than a day to 127 days and had a mean for all 19 beacons of 39 days. The beacons appeared to be on ice over their entire operation periods, except for #3319 and #8666 which probably began floating in open water on days 133 and 122 respectively, based on ice charts, hull temperatures and data reception.

After removing spikes from the position data, 6-hourly positions were computed using linear interpolation. The trajectories of the beacons for the three deployments, based on these 6-hourly positions, are plotted in Figures 8, 9 and 10. The trajectories of individual beacons are shown in Appendix B,

with the positions marked at 1800 GMT each day, and labelled every 10 days. The trajectories of the beacons deployed east and northeast of Hudson Strait (Fig. 8) followed the shelf break of the Labrador Coast where the Labrador Current is located. Advected along by the Labrador Current, these beacons reached their highest daily speeds of 66 to 94 cm/s (Table 6). The beacons deployed off Cartwright on February 12 and 14 (Fig.9) all remained over the shelf during their southerly drift. This is abnormal, but as stated earlier resulted from the reduced offshore winds for the 1991 winter. Similar the beacons deployed on March 15 and 16 (Fig. 10) remained over the shelf.

Daily mean velocity components were calculated starting at 2100 GMT for each of the beacons, while they were still on the ice (Table 6). Using the vector mean speeds and directions, the beacons which lasted more than 2 days drifted at 7 to 45 cm/s to the south or southeast with a mean of 17.5cm/s. Daily speeds were as high as 94 cm/s.

4.3 ICE BEACON ENVIRONMENTAL DATA

In addition to position data, 13 of 19 the beacons were collecting data from the ocean, ice cover and atmosphere. A list of sensors on the various ice beacons is shown in Table 1.

All the data except wind data were processed as follows. For each pass, the data record having the largest number of repeats was selected. Any remaining spikes were removed by comparing the data point with the five point median. Most of the data is shown as plots in Appendix C. A sample of the processed temperature data is shown in Figure 11 for the beacon #2393 in Cartwright harbour. Hourly ice temperatures were computed using linear interpolation and used to derive the daily mean profiles as shown in Figure 11, along with air temperature. The ice temperature profiles are plotted as solid lines every 2 days relative to -1.8 $^{\circ}$C lines, which are dotted, and 1 day represents 1 $^{\circ}$C. The profile data shows that ice accretion occurred until Jday 65, after which an 8-day period of onshore winds brought milder temperatures and caused the severe ice rafting along the Newfoundland coast. After this period the ice and air temperatures never became as cold as before Jday 65.

The hourly wind data from beacon #8666 were sorted using the internal clock time. For each hour, the record having the largest number of repeats was selected. The few missing values were filled using linear interpolation. Three hourly mean wind components are shown as stick plots in Figure 12 along with the 3-hourly drift velocities of the floe the beacon was on. The data covers a 76-day period during which the ice floe moved southwards a total of 880km, passing just outside St. John's harbour on Jday 110. Fig. 12 shows the high correlation between the wind and beacon drift. The 8-day period of onshore winds, starting on Jday 65, is clearly visible. Before and after this period, the winds were predominantly from the northwest as normal for the region.

Of the two temperature profile ice beacons deployed in Cartwright harbour (#2393 and #1052), the IMP #2393 displayed colder ice temperatures at the bottom and warmer ice temperatures at the top. This suggests that the IMP #2393 was conducting heat within the instrument. For the IMP, the thermistors lie between 2 PVC tubes, one inside the other, with batteries within the inner tube, while for the SIMP, the thermistors are potted in a groove in a wooden dowel. The battery pack of the IMP appears to be conducting heat heat from the ocean to the atmosphere, reducing the measured temperature gradient within the ice cover. The newer marginal ice zone beacon SIMP does not have this problem.

Salinity samples of the ice cover were obtained by collecting and melting ice chips in standard sea water bottles. The salinity values were both determined with a refractometer in the field and with the autosalinometer back at the Institute. Comparison of the values for the samples collected after the February deployment (Appendix F) show that the refractometer is a good instrument for obtaining ice salinities to accuracies of $\pm$.5ppt. Ice salinity values from Cartwright harbour station show that higher values occurred in the surface layers of the ice sheet (8.5 to 14.0ppt), while lower values occurred below the surface layer (5.9 to 9.9ppt). When the snow layer melted, the melt water washed the remaining salt out resulting in low ice salinity values of .3 to 1.3ppt by May 15. Ice salinity values for the offshore pack ice ranged from 7.0 to 18.9ppt and for the 20 samples had a mean of 11.7ppt., much higher than the value of 6-8ppt commonly used in ice growth models.

4.4 ICE AND WATER TEMPERATURE/SALINITY DATA

Five sets of ice and surface water salinity samples were collected in Cartwright harbour: on January 9, February 12 and 14, March 16 and May 15 (Appendix D). Ice salinity samples and CTD profiles were also collected at nine of the offshore deployment sites: three in February and six in March (Appendix D). During February, ice salinity samples and CTD profiles were collected at the outer and middle sites on February 12, and at the inner site on February 14. On March 15, ice salinity samples were collected from all three sites; however good CTD profiles were collected at the outer and middle sites only. On March 16, ice salinity samples and good CTD profiles were obtained for all three sites, with two CTD profiles at the outer site.

The CTD data were averaged in 0.5 m bins, and are shown as plots in Appendix E for both the downcasts (solid lines) and upcasts (dashed lines). In many cases, the downcast data were erroneous, because of slush in the system at the beginning of the cast. Freezing temperatures, also shown, were calculated as a function of salinity and pressure using the equations of Fujino et al (1974). The CTD data listed at intervals of 5 m (Appendix E) are from the upcast for all stations except CART03.

In February, the CTD profiles at the outer and middle sites showed a homogeneous layer of water with a temperature near the 0 dbar freezing point down to about 100 m, and a warmer saltier layer below. At the inner site the depth of the surface homogeneous layer was 130m. By March, the water was homogeneous and near the freezing point throughout the profile, down to about 150 m at all stations.

5.0 CONCLUSION

During the winter of 1991, the Bedford Institute of Oceanography deployed a total of 19 satellite-tracked ice beacons off the Labrador coast (3 on land-fast ice and 16 on drifting pack ice). Several different types of ice beacons were used, all of which telemetered their data via the Argos satellite system and provided position data.

The beacons collected a total of 748 buoy-days of data (an average of 39 days per beacon) before the beacons either malfunctioned, dropped off the ice or were recovered (4 beacons). Of the two ice temperature profile beacons deployed on land-fast ice in early January, one of them failed near the end of March, while the other continued to operate until it was recovered on May 15. In general, the beacons deployed on mobile pack ice drifted southwards for 200km km, with two beacons reaching the latitude of St. John's, 47.5 $^{\circ}$N. The vector mean speed of the beacons ranged from 6-39 km/day, with a maximum daily mean speed of 81 km/day. The anemometer beacon operated for 72 days before the ice floe on which it was placed melted. Of the four ice temperature profile beacons deployed on drifting ice, two failed after less than two days of operation. The other two lasted for 30 and 34 days, when they were probably crushed during onshore ice drift.

Temperature and salinity profiles in the water column beneath the ice were collected using a Seabird CTD at eight of the beacon deployment sites. Ice thicknesses and salinities were also measured. In February, there was a homogeneous layer of water at the freezing point down to 130 m at the station closest to shore, while farther from shore there was a warmer saltier layer below about 100 m. In March, the water was homogeneous and at the freezing point at all the stations down to about 150 m. Ice salinities of the offshore pack ice were on the average 11.7ppt.; it is higher than expected and may be an indication that the ice sampled grew fast and is relatively young first year ice.

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Table 1. Areas, start and end times in 1991 calendar days, types and sensors (x) for ice beacons on both land-fast and drifting ice. Area numbers are 1 for Cartwright, 2 for Hudson/Davis Straits and 3 for Labrador pack ice. The times represent the times when the beacons were transmitting; in some cases, the sensors did not work over the whole period.

					Sensors				
Area	Beacon ID	Type	Start Jday	End Jday	Bar. P.	Air T.	Hull T.	Ice T.	Wind
1	8663	Atm.	9	12	x	x	-	-	x
1	2393	IMP	9	135	-	x	-	x	-
1	1052	SIMP	29	82	x	x	x	x	-
2	5217	Air-d.	33	134	-	-	-	-	-
2	5218	Air-d.	33	81	-	-	-	-	-
2	5215	Air-d.	34	48	-	-	-	-	-
2	5216	Air-d.	34	51	-	-	-	-	-
3	5437	IMP	43	73	-	x	-	x	-
3	4761	CMIB	43	56	x	x	x	-	-
3	2376	Loc.	43	74	-	-	-	-	-
3	1054	SIMP	45	47	x	x	x	x	-
3	2377	Loc.	45	69	-	-	-	-	-
3	8666	Atm.	45	151+	x	x	-	-	x
3	3319	Loc.+	74	151+	-	-	x	-	-
3	3320	Loc.+	74	89	-	-	x	-	-
3	1055	SIMP	74	108	x	x	x	x	-
3	4762	CMIB	75	101	x	x	x	-	-
3	1053	SIMP	75	75	x	x	x	x	-
3	8648	Loc.+	75	120	-	-	x	-	-

Table 2. Accuracy and resolution of ice beacon data parameters.

Data parameters	Accuracy	Resolution
Latitude	0.2 km	0.001 $^{\circ}$
Longitude	0.2 km	0.001 $^{\circ}$
Barometric pressure	1.5 mb	0.15 mb
Air temperature	1.0 $^{\circ}$C	0.3 $^{\circ}$C
Hull temperature	1.0 $^{\circ}$C	0.2 $^{\circ}$C
Ice temperature*	1.0 $^{\circ}$C	0.1 $^{\circ}$C
Wind: speed ($<$10 m/s)	1.0 m/s	0.48 m/s
speed ($>$10 m/s)	10%	10%
Wind direction	5 $^{\circ}$	$<$1 $^{\circ}$

* sensor accuracy 0.2 $^{\circ}$C

Table 3. Observed and ice chart ice thicknesses for February and March of 1991. Sizes of the floes on which the beacons were deployed are listed.

		——OBSERVED——			——ICE CHART——		
Date	Stn. #	Thick-ness cm	Floe size kmxkm	Snow cm	Type	Thick-ness cm	Conc. %
Feb. 12							
	9102	104	.2x.2	1	1.	70-120	20
					7	30-70	50
	9103	68	1x1	4	7	30-70	50
					5	15-30	50
	9104	43	.1x.1	5.5	5	15-30	50
Feb. 14							
	9105	72	--	17	7	30-70	10
					5	15-30	60
	9106	46	1x1	10	7	30-70	10
					5	15-30	40
	9107	50	1x1	1	7	30-70	10
					5	15-30	40
Mar. 15							
	9108	136	.03x.04	0	4.	>120	10
	9109	184	.03x.05	4	1.	70-120	50
	9110	86	.06x.09	4.5	7	30-70	40
Mar. 16							
	9111	52	2x2	7			
	9112	52	1.5x2	7	4.	>120	20
	9113	61	1.5x2	5	1.	70-120	70

Table 4. Air temperature anomalies at stations along the Canadan east coast from "Climatic Perspectives" published monthly by Atm. Env. Ser. (1991a).

WINTER 1990-1991 AIR TEMPERATURE ANOMALIES ($^{\circ}$C)

AREA	Baffin Bay	Davis Strait	Hudson Strait	Labrador S. Coast	Newfoundland NE. Coast
Station	Clyde	C. Dyer	Iqaluit	Cartwright	St. John's
October	-3.8	-1.8	-1.5	0.3	1.8
November	-2.6	0.1	0.7	0.3	-0.5
December	-2.5	-5.0	-5.6	-2.1	0.4
January	-4.7	-5.8	-6.5	-7.8	-4.2
February	-0.3	-2.0	-3.1	-2.0	-1.3
March	-1.7	-1.0	0.2	1.6	0.7
April	2.0	-3.0	-3.5	-2.6	-0.8
May	-0.9	-3.0	-3.8	-2.0	-0.9
June	3.0	2.8	2.8	-2.5	-1.9
July	2.0	3.1	1.7	-3.8	-1.9
Jan.-Mar.	-2.2	-2.9	-3.1	-2.7	-1.6
Apr.-Jun.	1.4	-1.1	-1.5	-2.4	-1.2

Table 5. Monthly displacements of ice due to wind forcing. Monthly mean wind speeds for 16 directions were used, each an average over an 22.5 $^{\circ}$ sector, multiplied by their frequency of occurrence and by 2.5% to convert wind speed to ice speed and turned 35 $^{\circ}$ to the right of the wind to represent ice drift direction.

	NE. NEWFOUNDLAND SHELF (GANDER WIND)				S. LABRADOR SHELF (CARTWRIGHT WIND)			
	1955-1980		1990/1991		1955-1980		1990/1991	
MONTH	DIST. (KM)	DIR. (DEG)	DIST. (KM)	DIR. (DEG)	DIST. (KM)	DIR. (DEG)	DIST. (KM)	DIR. (DEG)
NOV.	140	100	170	115	170	120	315	195
DEC.	180	105	220	95	190	125	280	115
JAN.	170	115	280	120	170	125	280	125
FEB.	155	125	210	115	165	130	240	125
MAR.	115	140	115	210	170	150	140	190
APR.	95	150	100	195	140	180	190	175
MAY	65	125	95	135	110	185	170	190
JUN.	120	75	50	125	50	150	210	200
JAN-MAR	145	125	200	145	170	135	265	145
APR-JUN	90	115	80	155	100	170	190	190

1955-80 winds are from "Canadian Climate Normals" (Atm. Env. Ser., 1982b).
1990-91 winds are from "Monthly Records" (Atm. Env. Ser., 1991b)

Table 6. Mean and standard deviation of velocity components, vector mean speed and direction, minimum and maximum daily speed and number of days for the 1991 ice beacons. U and V are the velocity components, such that positive U is toward the east, and positive V is toward the north.

Beacon ID	$\bar{U}$ cm/s	s.d.(U) cm/s	$\bar{V}$ cm/s	s.d.(V) cm/s	Speed cm/s	Dir. °T	Min Sp. cm/s	Max Sp. cm/s	Days
1054	-3.1	-	-2.9	-	4.2	227	4.2	4.2	1
1055	-1.0	9.8	-7.9	11.7	8.0	187	0.7	40.1	34
2376	-1.4	15.9	-14.2	20.7	14.3	186	4.2	55.7	29
2377	4.1	14.9	-17.4	19.9	17.9	167	4.8	73.0	23
3319	3.4	11.7	-10.8	16.8	11.3	163	0.9	75.3	57
3320	-1.3	4.8	-7.2	16.6	7.3	190	1.6	31.5	13
4761	12.9	19.3	-24.2	25.6	27.4	152	6.8	84.8	12
4762	3.7	10.6	-9.3	18.7	10.0	158	2.1	64.8	24
5215	23.8	15.5	-38.3	27.0	45.0	148	19.4	94.4	13
5216	10.8	23.4	-15.6	30.3	19.0	145	6.8	86.6	16
5217	5.4	14.2	-17.7	18.8	18.5	163	2.0	77.1	101
5218	4.2	14.4	-22.8	15.6	23.2	170	4.1	66.1	47
5437	5.8	22.6	-16.2	20.8	17.2	160	5.2	73.7	28
8648	1.6	7.2	-11.7	15.5	11.8	172	2.5	52.7	45
8666	2.9	12.8	-13.2	17.6	13.5	168	0.4	78.7	76

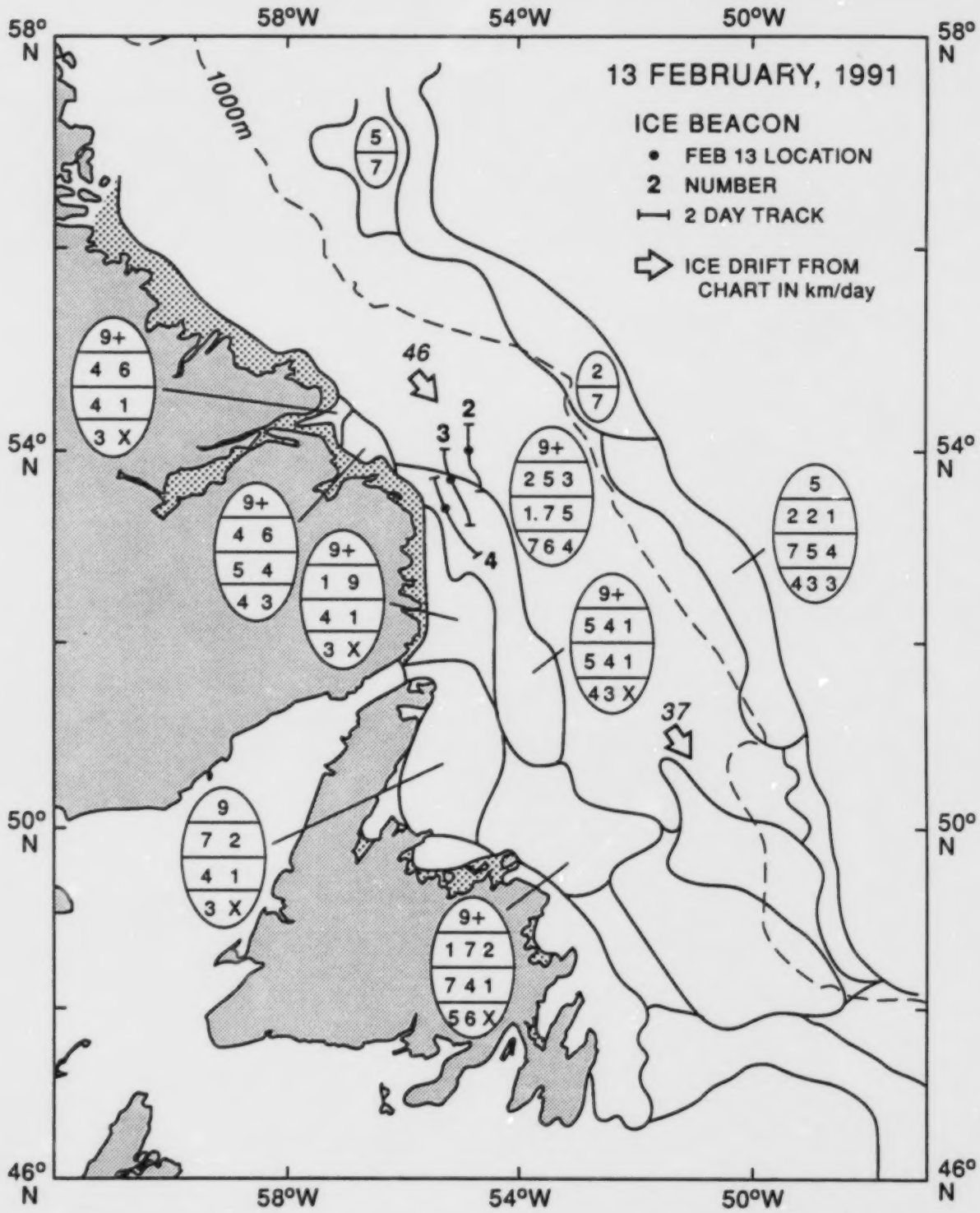


Fig. 1. Ice chart of February 13, 1991, showing the positions and 2-day displacements of the beacons deployed on February 12.

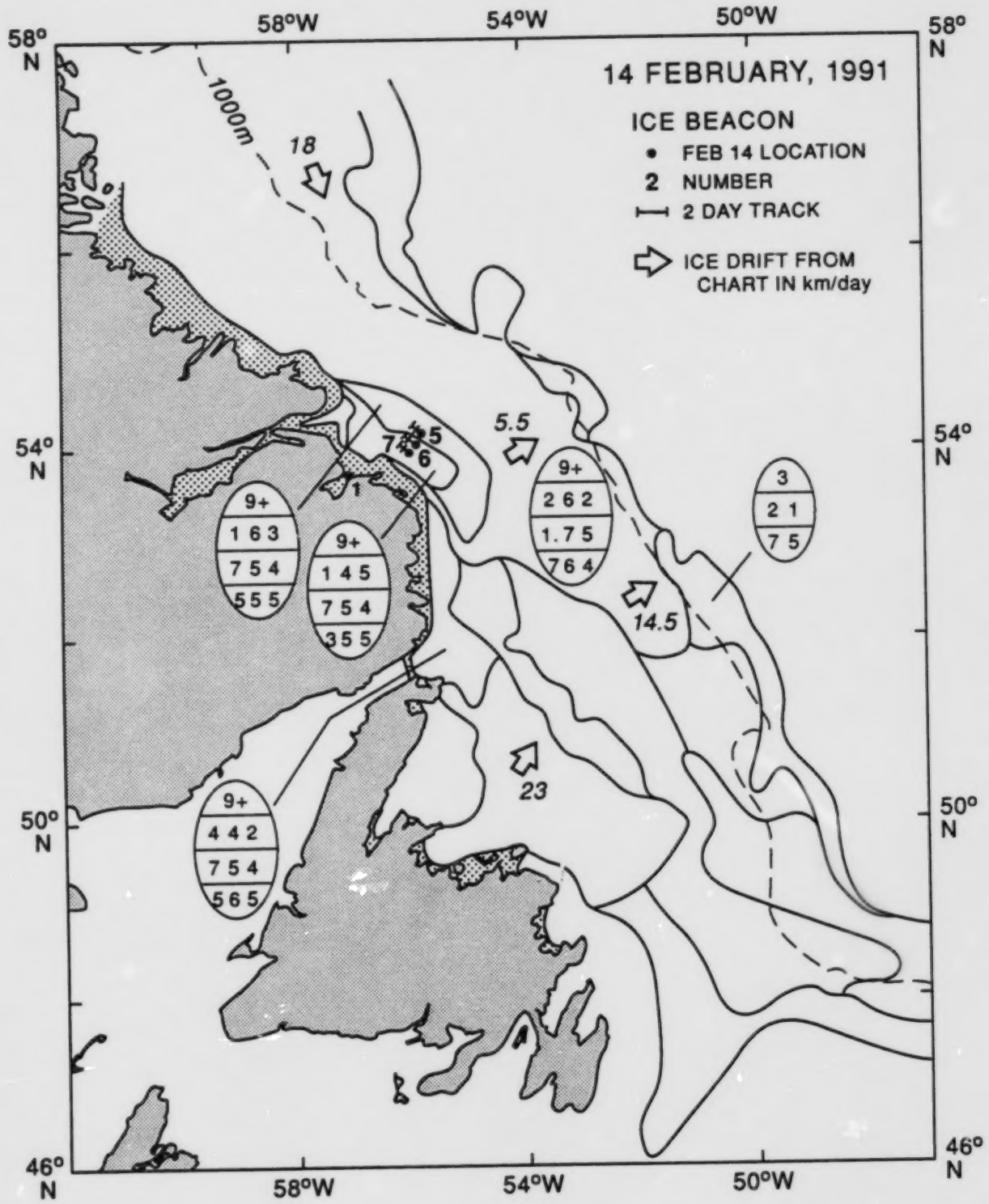


Fig. 2. Ice chart of February 14, 1991, showing the positions and 2-day displacements of the beacons deployed on February 14.

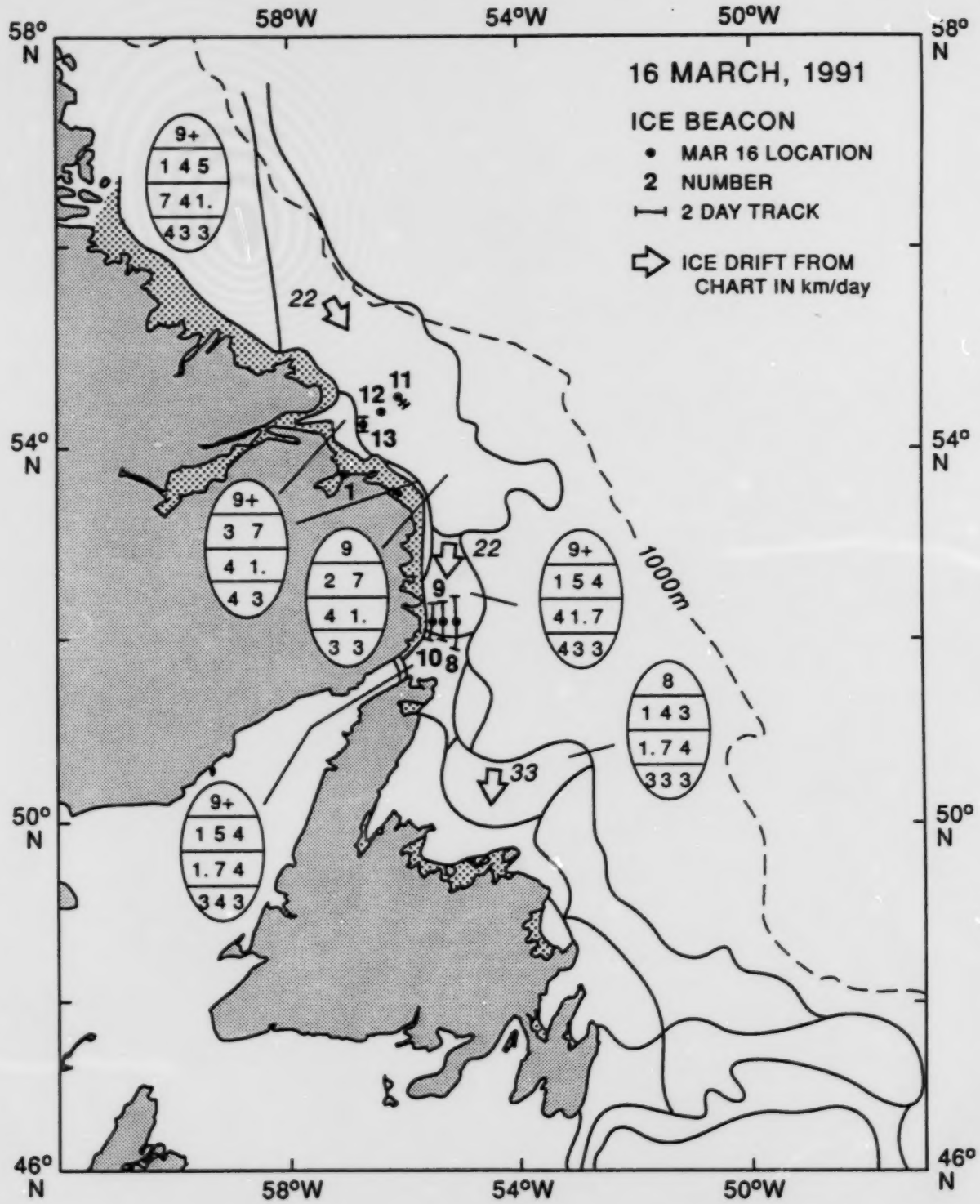


Fig. 3. Ice chart of March 16, 1991, showing the positions and 2-day displacements of the beacons deployed on March 15 and 16.

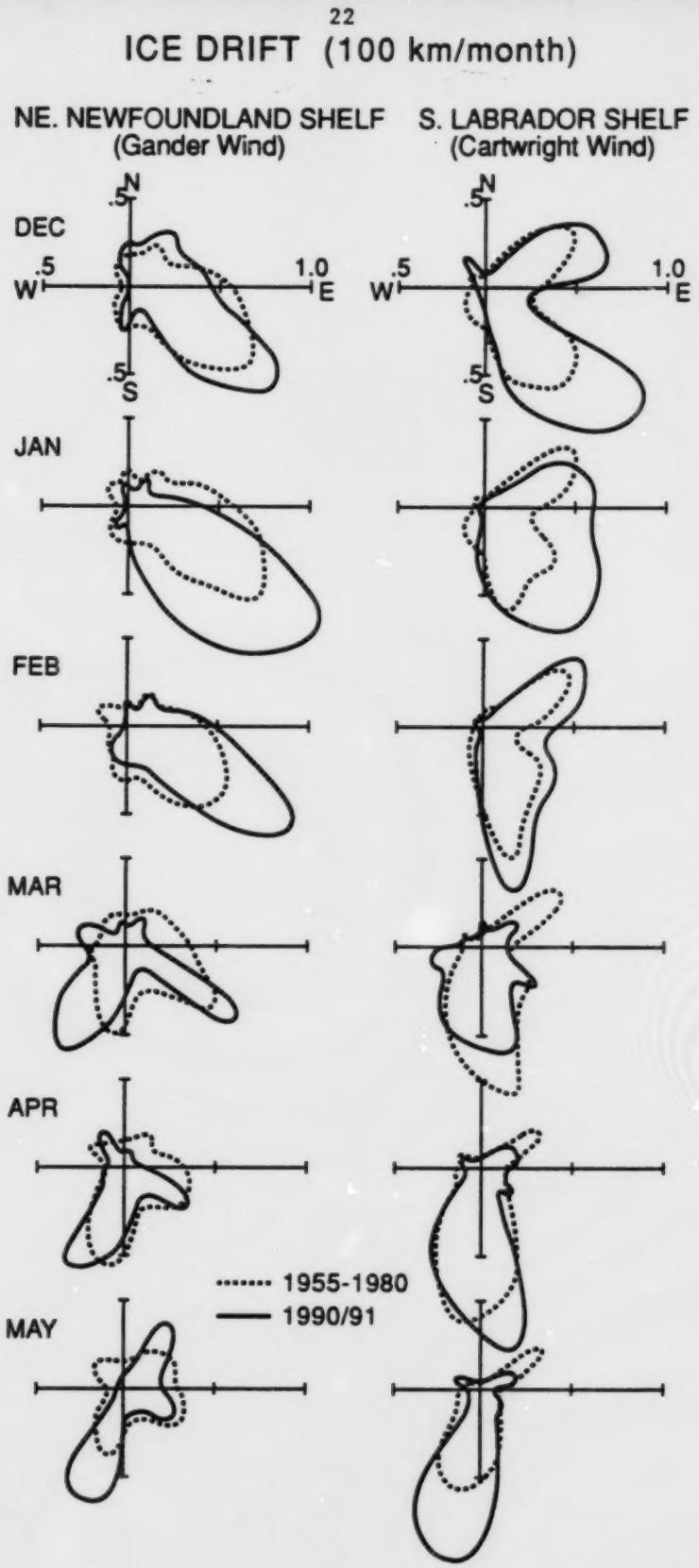


Fig. 4. Monthly contours representing the end points of 16 ice drift vectors in km/months for the 25-year mean and the 1990/91 winter.

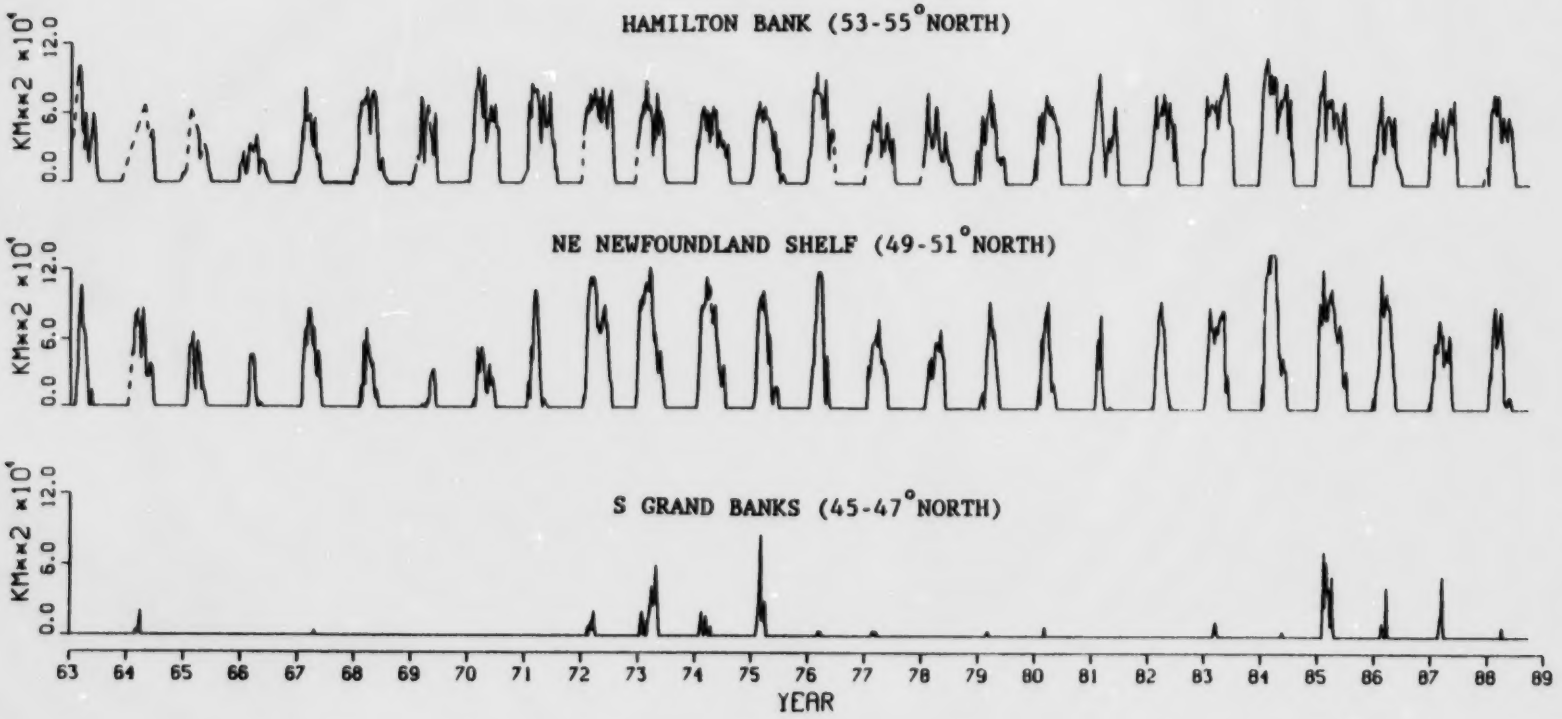


Fig. 5. Seasonal ice cover extent in $10^4 km^2$ (weekly values) for three areas along the Labrador/Newfoundland coast: Hamilton Bank area from 53 to 55 °N, NE Newfoundland shelf from 49 to 51 °N and S Grand Bank from 45 to 47 °N.

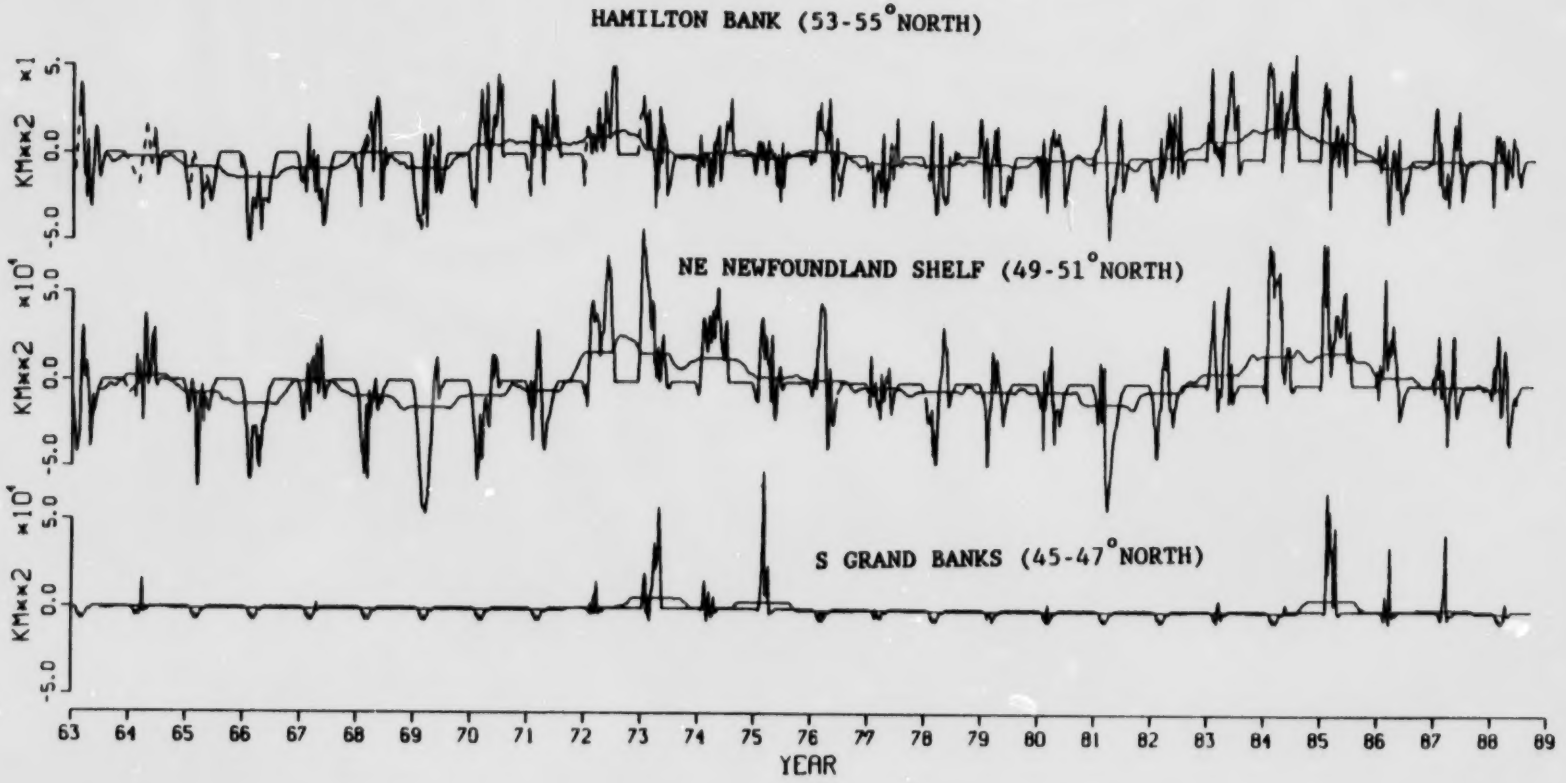


Fig. 6a Seasonal ice cover anomalies in $10^4 km^2$ for three areas along the Labrador/Newfoundland coast. Weekly values and 1-year running mean are shown for 1963 to 1988.

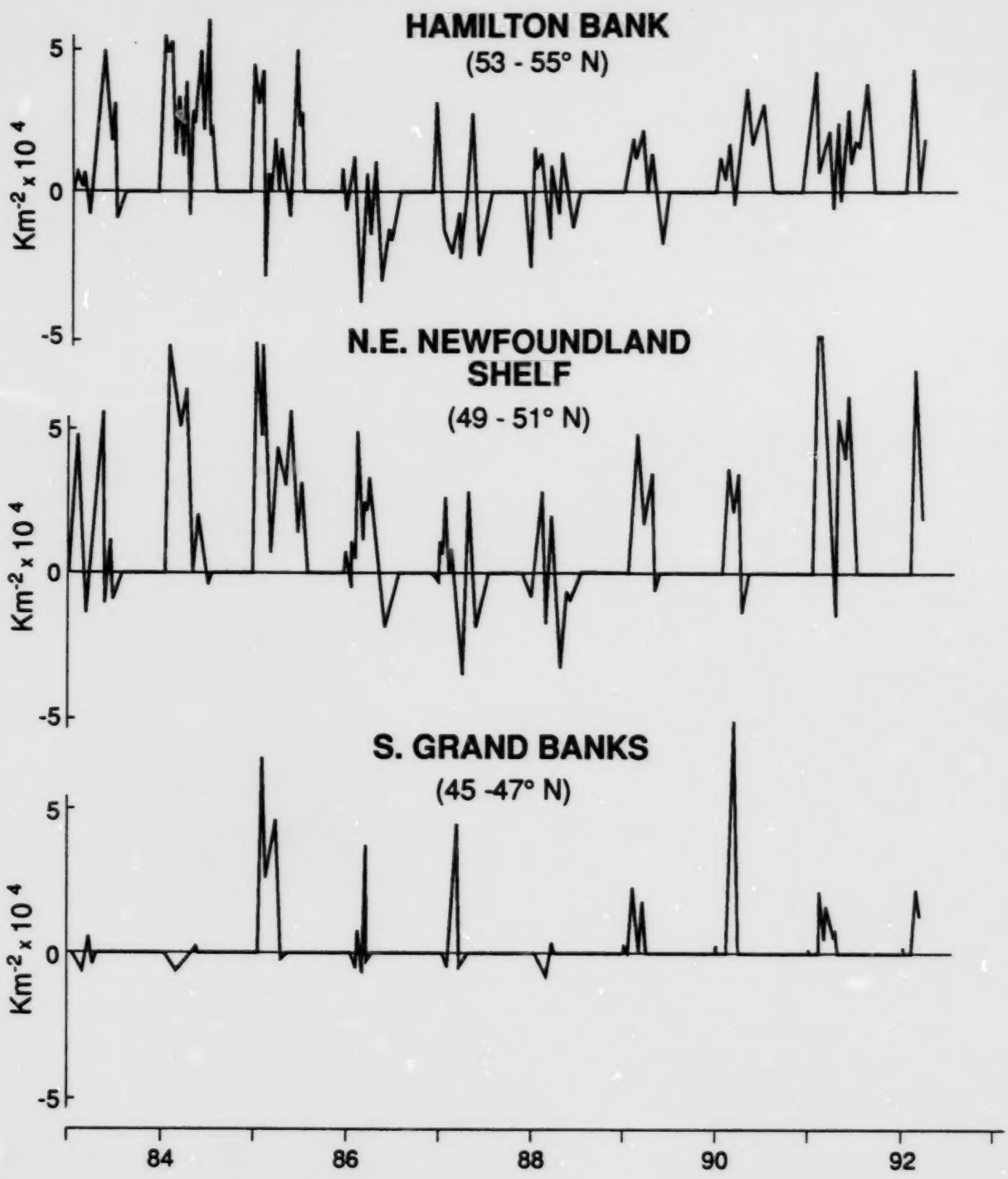


Fig. 6b Seasonal ice cover anomalies in $10^4 km^2$ for three areas along the Labrador/Newfoundland coast. Weekly values and 1-year running mean are shown for 1983 to 1991.

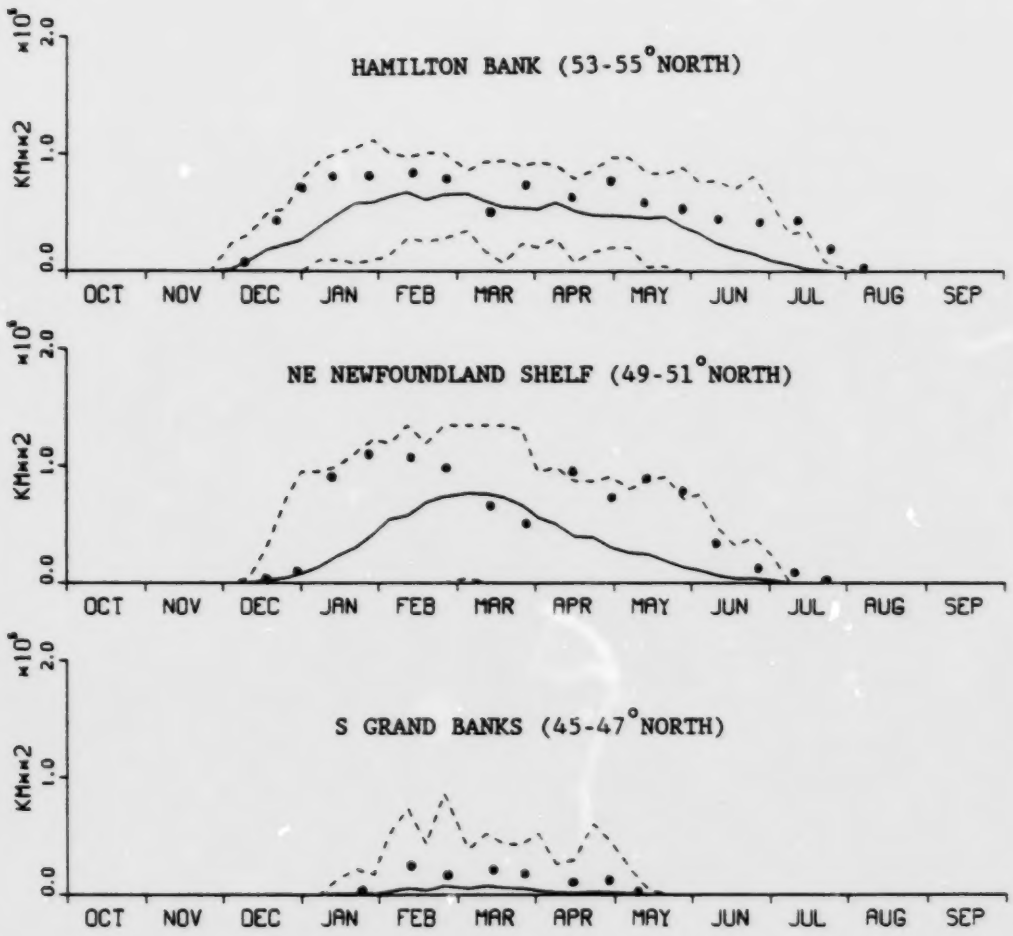


Fig. 7. Weekly mean ice extent with solid lines showing the 20-year mean, dashed lines the minimum and maximum ice extent in total 20-year records and dots the biweekly winter values of 1990/91.

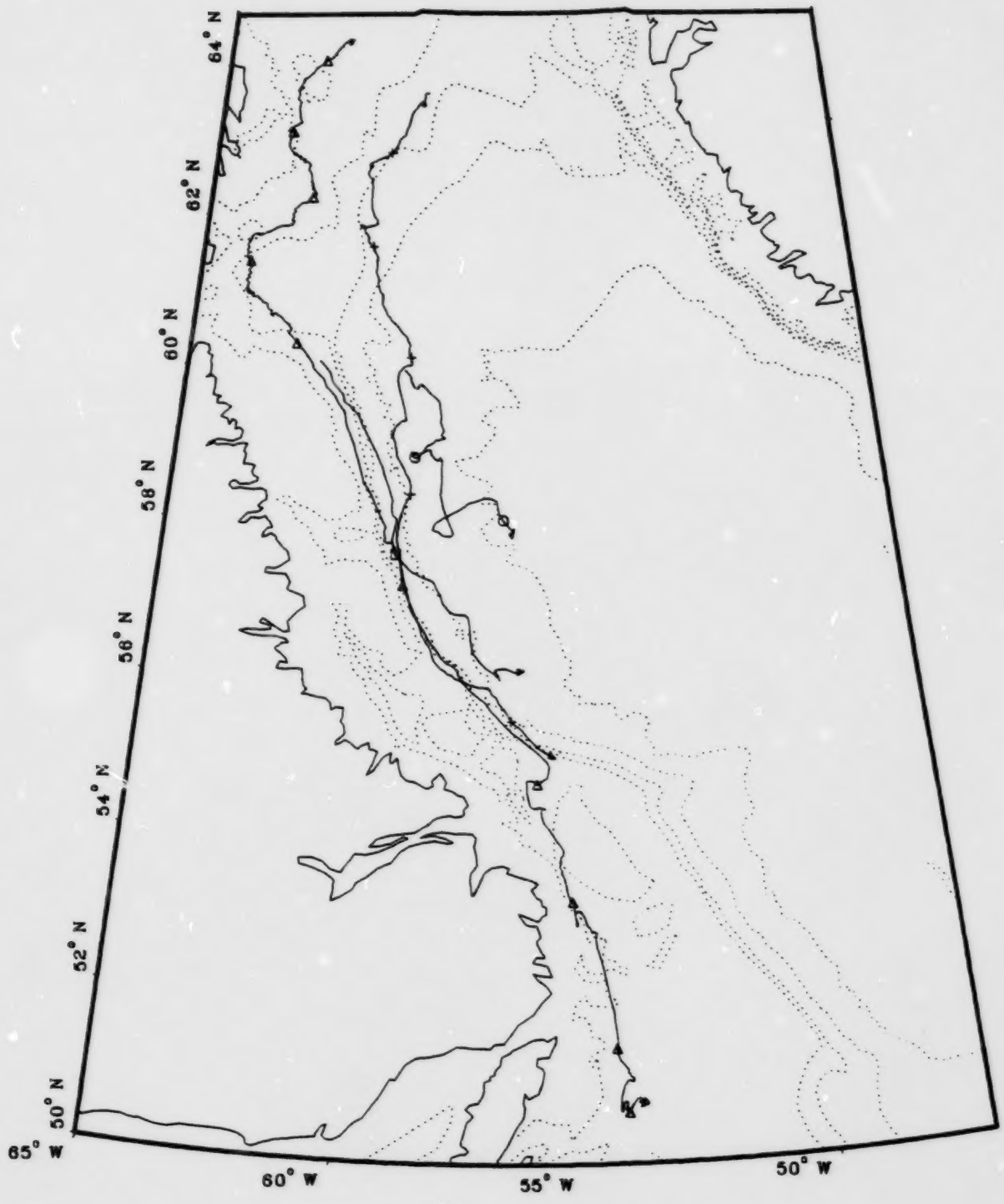


Fig. 8. Trajectories of ice beacons (5215, 5216, 5217 and 5218) deployed in February 2 and 3, with positions marked every 10 days.

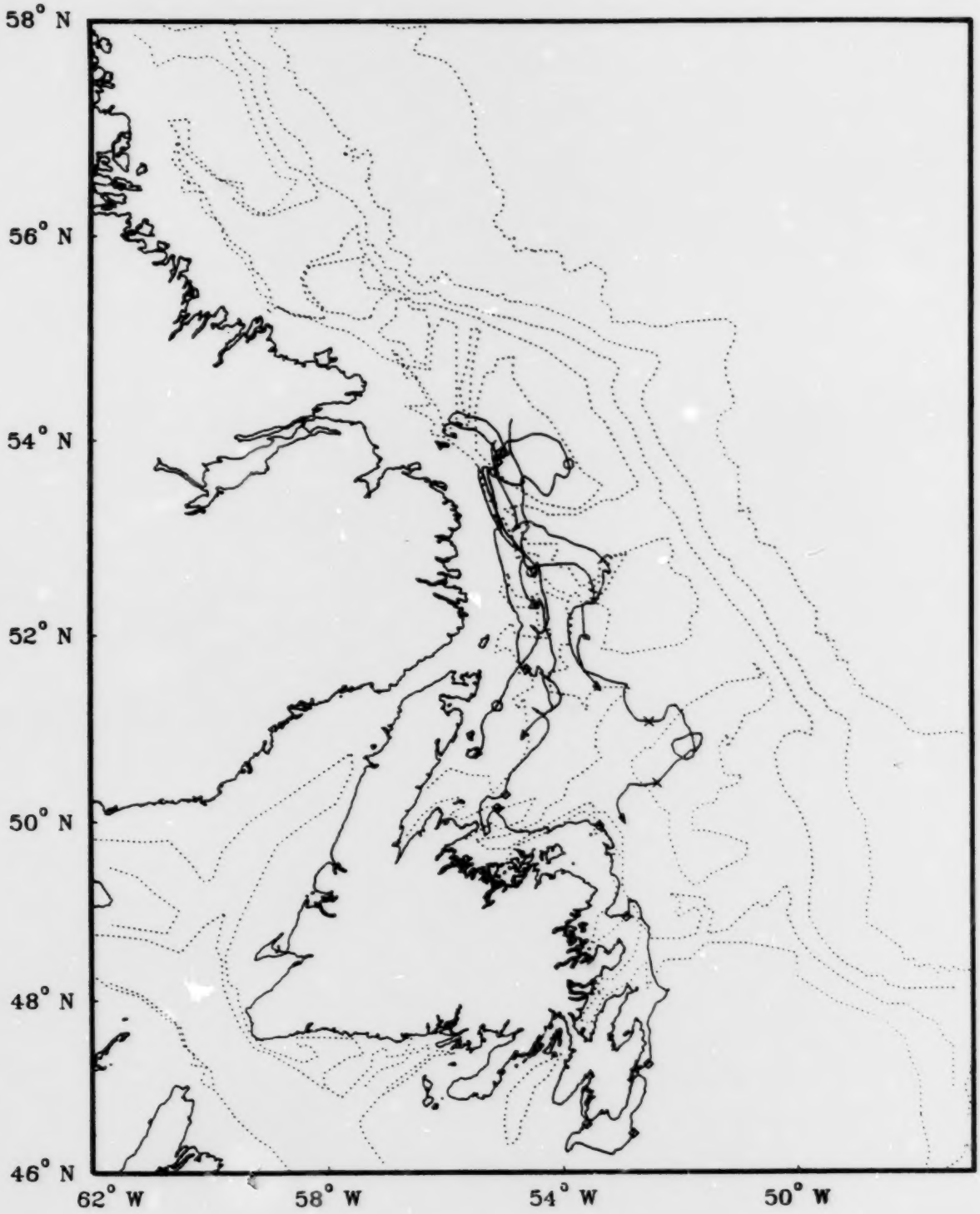


Fig. 9. Trajectories of ice beacons (1054, 2376, 2377, 4761, 5437 and 8666) deployed on February 12 and 14, with positions marked every 10 days.

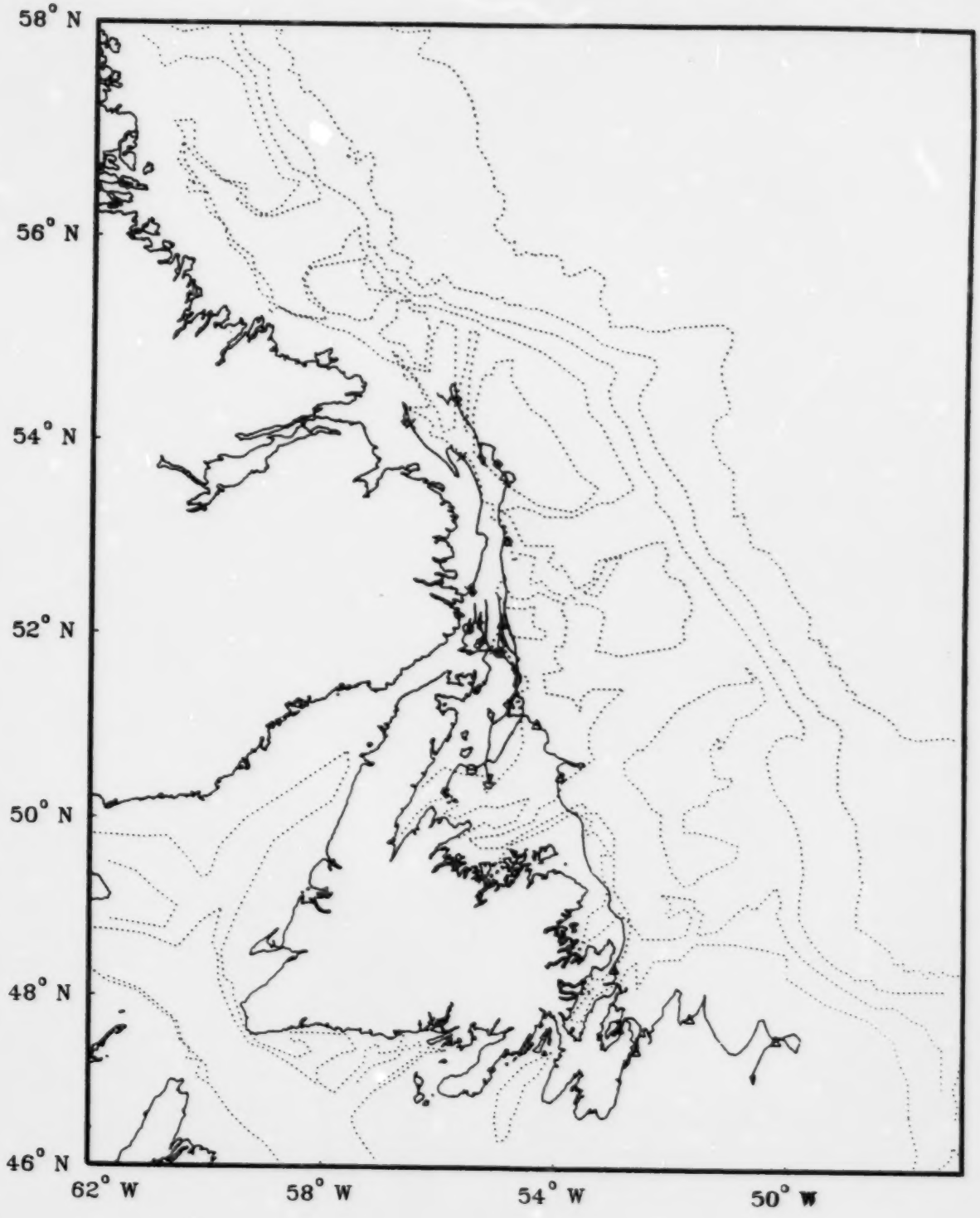


Fig. 10. Trajectories of ice beacons (1055, 3319, 3320, 4762 and 8648) deployed on March 15 and 16, with positions marked every 10 days.

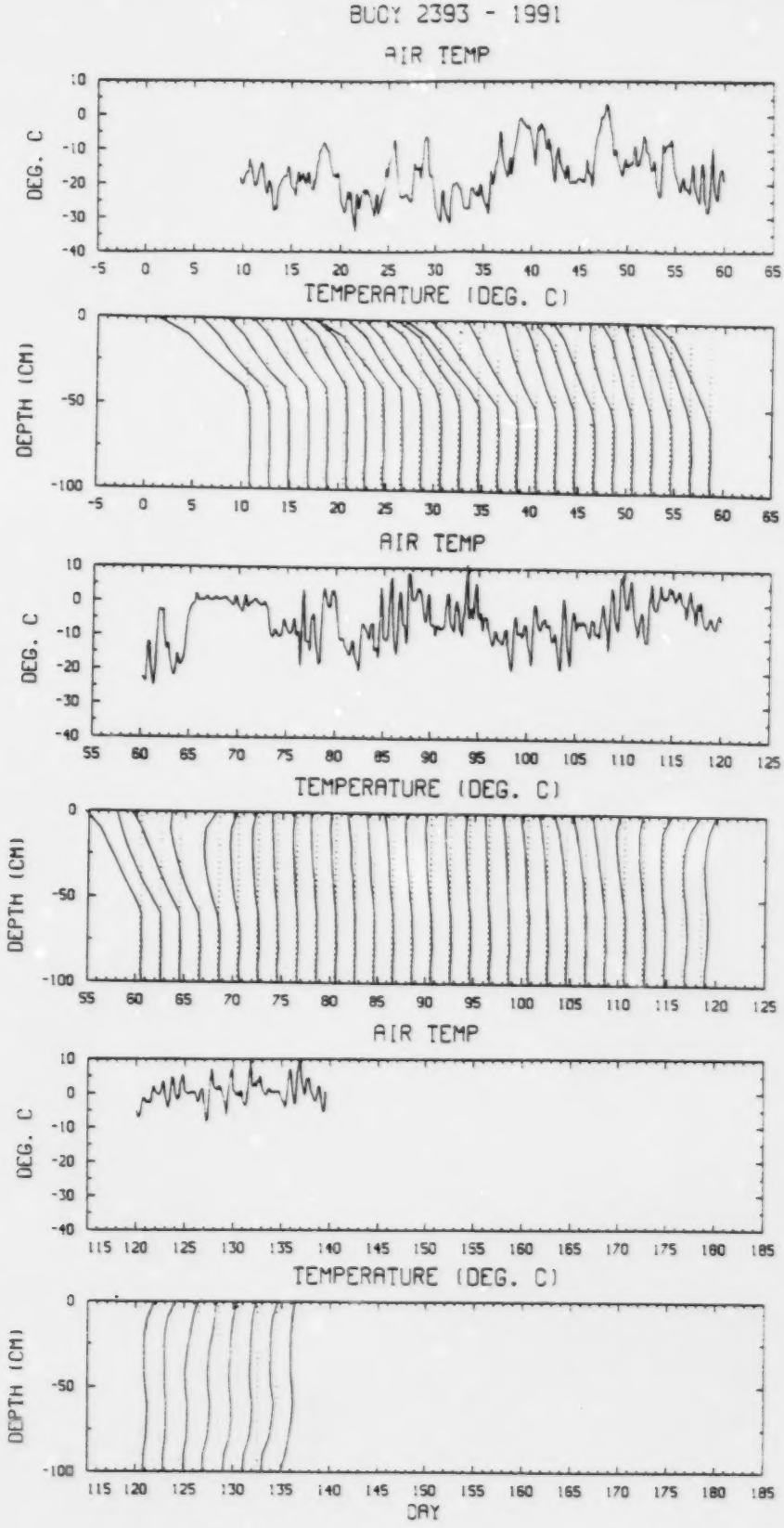


Fig. 11. Air temperature and ice/water temperature profiles from ice beacon #2393 in Cartwright harbour.

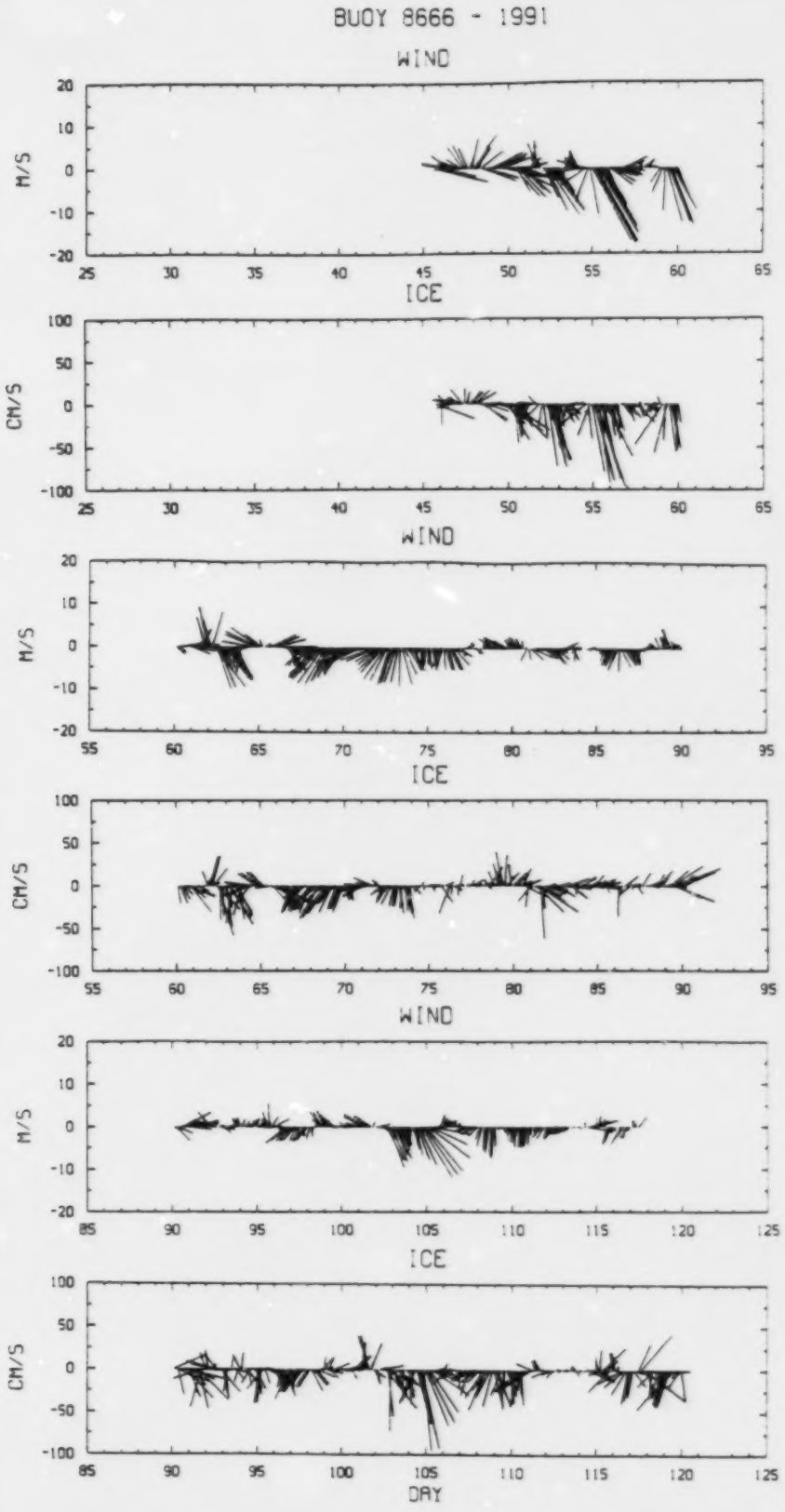


Fig. 12. Stick plots of wind and ice velocity (3-hourly) from beacon #8666.

APPENDIX A: FIELD PROGRAM SCHEDULE

January 9 - I. Peterson and P. d'Entremont of BIO deployed three beacons on land-fast ice in Cartwright harbour, Labrador.

Stn. 9101:-Atmospheric beacon, ARGOS #8663
-Large IMP (Ice Monitoring Platform), ARGOS #2393
-Small IMP, ARGOS #11056 (Number corrected later)
-Surface water and 4 ice samples; CTD malfunctioned.

January 11 - Small IMP not on ARGOS account; all numbers of the small IMPs have an extra digit.

January 12 - Atmospheric beacon #8663 stopped transmitting; air temperatures were down to -28 ^{o} C.

January 29 - Small IMP with corrected # 1052 was installed at Cartwright, but mast was not fully extended (data transmitted) until February 2.

February 2 - Canadian Ice Centre's reconnaissance aircraft air dropped beacons #5217 and #5218 northeast of Hudson Strait.

February 3 - Canadian Ice Centre's reconnaissance aircraft air dropped beacons #5215 and #5216 east of Hudson Strait.

February 11- Beacons and CTD tested at Goose Bay for offshore deployment trip. Anemometer beacon #8664 not working, exchanged for anemometer beacon #8666.

February 12- February ice beacon deployment trip of southern Labrador (Black Tickle). Two Universal helicopters, pilots: Ron Moores and Paul Garrett, and S. Prinsenberg and M. Scotney of BIO.

Stn. 9102: -About 58 miles offshore; location beacon #2376
-104cm of ice and 1cm of snow
-Surface water and 2 ice samples
-Salinity/temperature profiles

Stn. 9103: -About 40 miles offshore; large IMP #5437
-68cm of ice; and 4cm of snow
-Salinity/temperature profiles
-Surface water and 3 ice samples

Stn. 9104: -About 25 miles offshore; small location beacon #4761
-43cm of ice and 5.5cm of snow
-No salinity/temperature profiles taken (too late)

Stn. 9101: -Cartwright; 60cm of ice, 21cm of snow (snow layer depresses snow/ice interface below water level)
-3 ice samples; removed anemometer beacon #8663

February 13- Snow storm; stuck at Cartwright.

February 14- Deployment off Cartwright (-25 °C, snowing and windy)

Stn. 9101: -Cartwright harbour; surface water and 4 ice samples

Stn. 9105: -About 50 miles offshore; stopped by snow storm
-Large location beacon #2377
-72cm of ice and 17cm of snow
-No CTD or ice samples; weather too bad

Stn. 9106: -About 35 miles offshore; anemometer beacon #8666
-46cm of ice and 10cm of snow
-No CTD or Ice samples (too windy and cold)

Stn. 9107: -About 20 miles offshore; small IMP #1054
-50cm of ice, 1cm of snow (stopped snowing but windy)
-3 ice samples; salinity/temperature profiles

March 14 - Beacons and CTD tested at Goose Bay for March offshore deployment trip. Beacon #8648 tested and taken as spare.

March 15 - March ice beacon deployment trip of southern Labrador coast: Two Universal helicopters, pilots: Ron Moores and Jim Myra, and S. Prinsenberg and P. Keenan of BIO.

March 15 - Weather down at Cartwright; went instead to Mary's Harbour with better weather approaching from the south. Ice edge only 20 miles from coast, 1m sea swell and pancake ice at ice edge.
- Temperature -12 °C, snowing lightly off and on.

Stn. 9108: -About 15 miles offshore; large location beacon #3319
-136cm of ice but no snow on the ice
-4 ice samples; salinity/temperature profiles

Stn. 9109: -About 10 miles offshore (seal herd)
-Large location beacon #3320; not safe to leave IMP
-Old ice 185cm thick and 4cm of refrozen snow
-Salinity/temperature profiles
-2 ice samples; rest of ice too wet

Stn. 9110: -About 5 miles offshore; small IMP #1055
-86cm of ice and 4.5cm of snow
-3 ice and 2 biological samples; rest of ice too wet
-CTD malfunctioned

March 16 - Cloudy to Black Tickle but Cartwright clear, NW winds and -9 °C.

Stn. 9101: -Cartwright; 68cm of ice plus 22cm of refrozen snow for a total of 90cm of ice with 4cm of dry snow
-Surface water and ice sample (ice wet but drained)

Stn. 9111: -50 miles off Gannet Island no ice edge yet; ice bergs every 3-5 miles aligned parallel to coast
-Large location beacon #8648
-52cm of ice and 7cm of fresh snow
-3 ice samples (wet); salinity/temperature profiles

Stn. 9112: -About 35 miles off Gannet Island
-Small IMP beacon #1053
-52cm of ice and 7cm of very hard refrozen snow
-Salinity/temperature profile

Stn. 9113: -About 15 miles of Gannet Island
-Small location beacon #4762
-2 ice samples; salinity/temperature profile
-Helicopter problem on take off (2hr delay)

May 15 - Recovery of ice beacons from Cartwright harbour. One Universal helicopter; pilot G. Baikie and S. Prinsenberg of BIO.

Stn. 9101: -Cartwright harbour, recovery of ice beacons #1052 and #2393. Large IMP (#2393) left in Cartwright.
-4 ice samples; sea and surface melt water samples.
-78cm of ice; back to original ice/air level: all snow or refrozen snow practically melted.

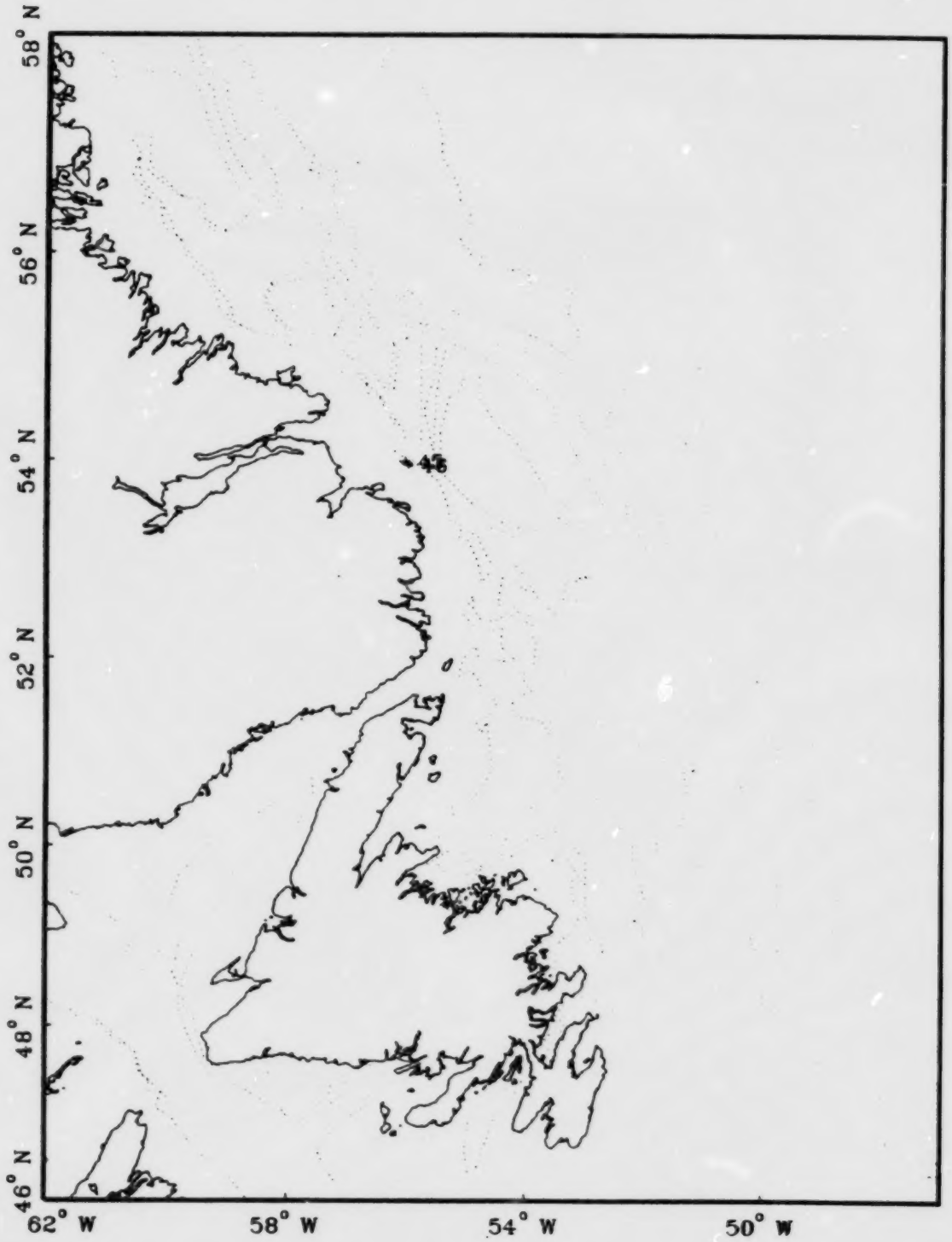
APPENDIX B: ICE BEACON TRAJECTORIES

Trajectories of the ice beacons deployed on drifting pack ice in 1991, with positions at 1800 hours GMT marked every day, and labelled every 10 days.

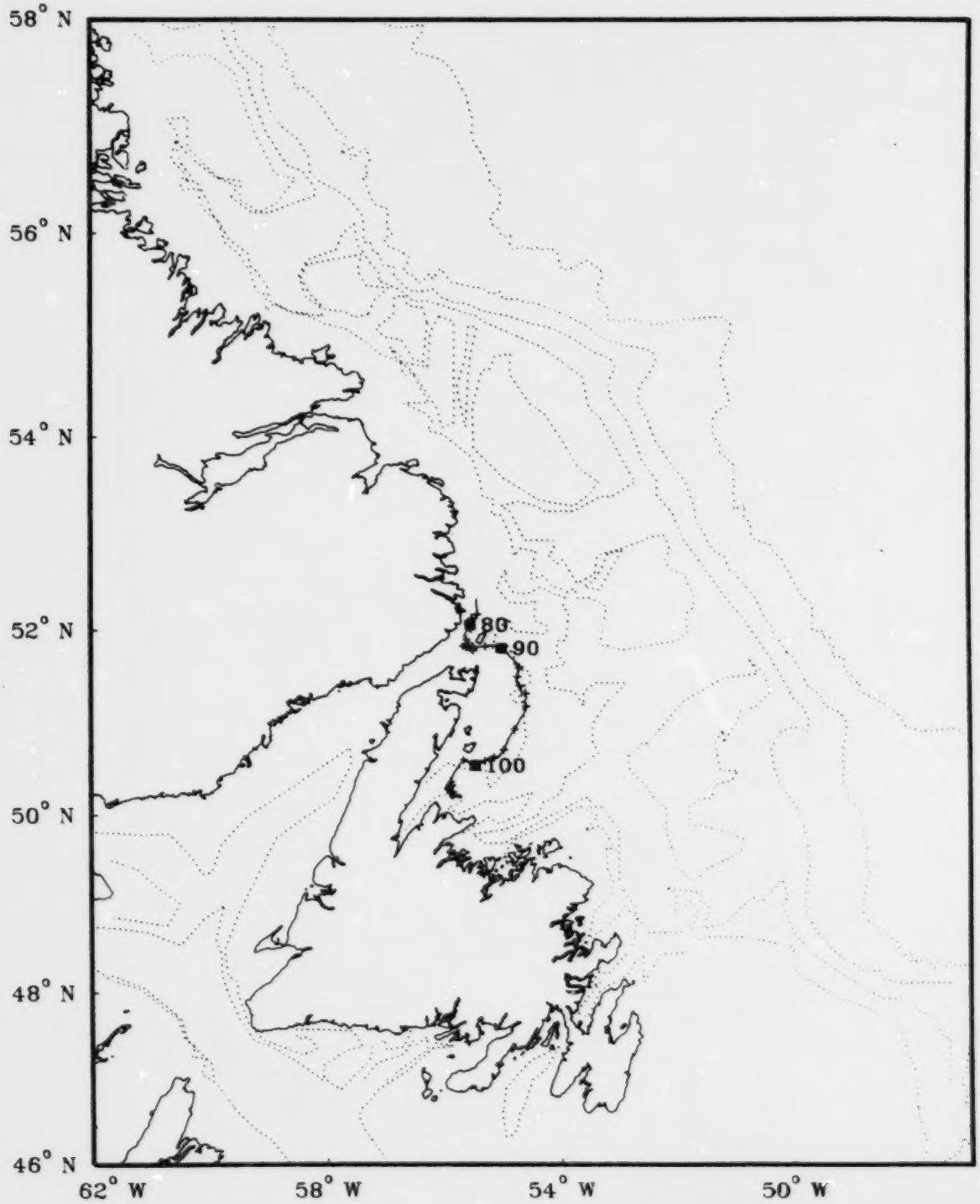
Beacon ID #	Start Time*	End Time*	Type
1054	45	47	Ice staff (SIMP)
1055	74	108	Ice staff (SIMP)
2376	43	74	Location
2377	45	69	Location
3319	74	151+	Location+
3320	74	89	Location+
4761	43	56	Location (CMIB)
4762	75	101	Location (CMIB)
5215	34	48	Loc., air-dropped
5216	34	51	Loc., air-dropped
5217	33	134	Loc., air-dropped
5218	33	81	Loc., air-dropped
5437	43	73	Ice staff (IMP)
8648	75	120	Anemometer
8666	45	151+	Anemometer

* times in 1991 calendar days.

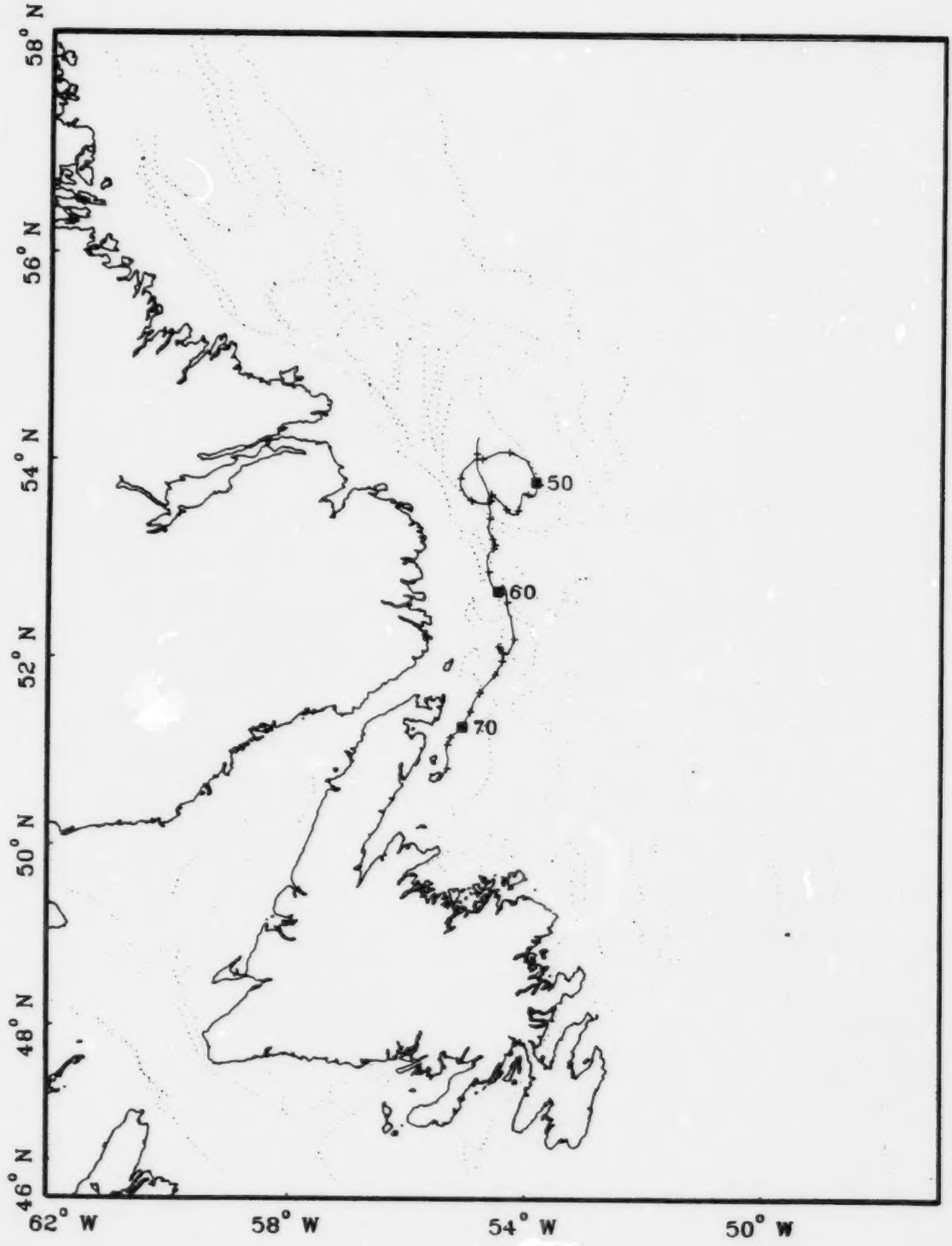
BUOY 1054 – 1991



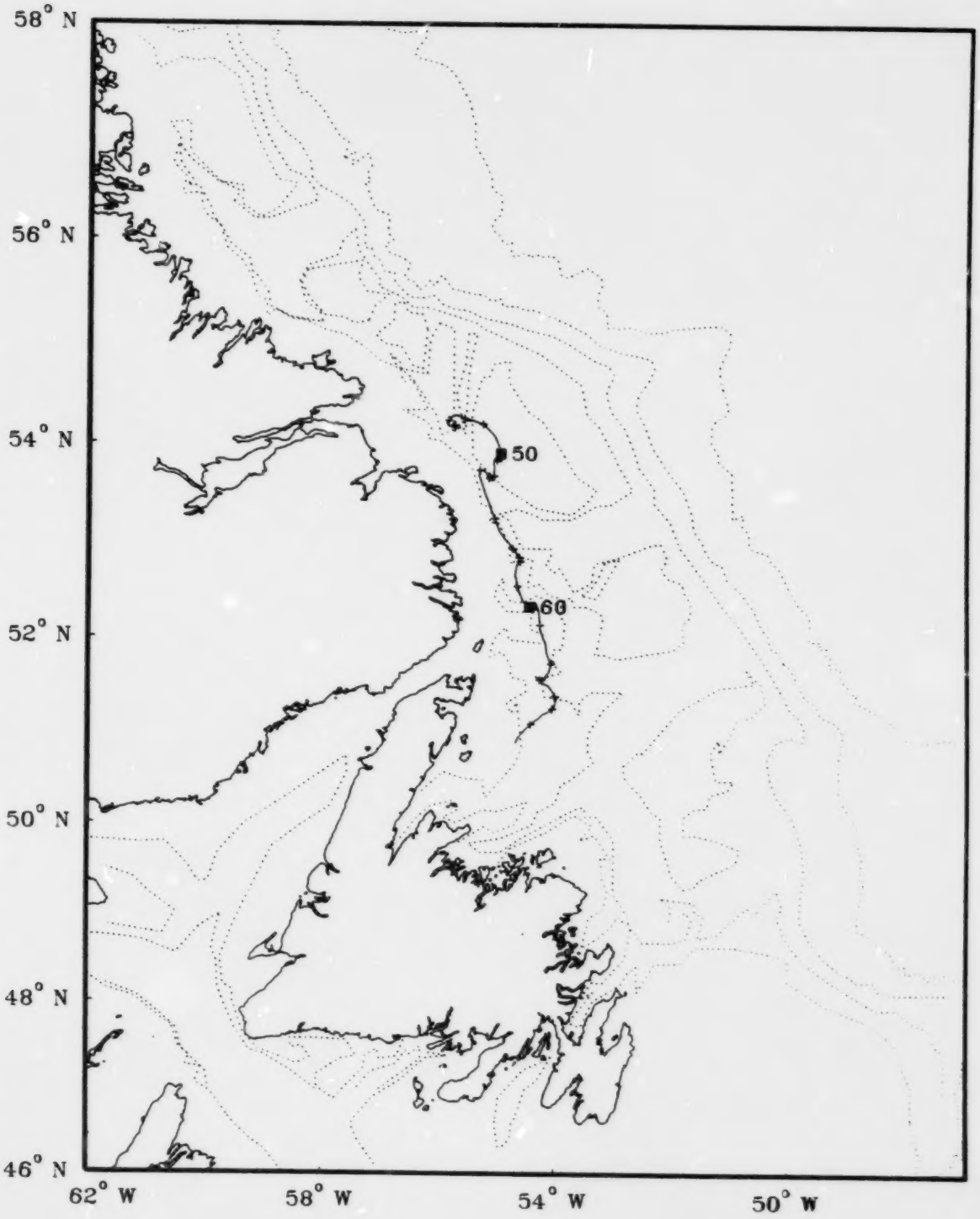
BUOY 1055 – 1991



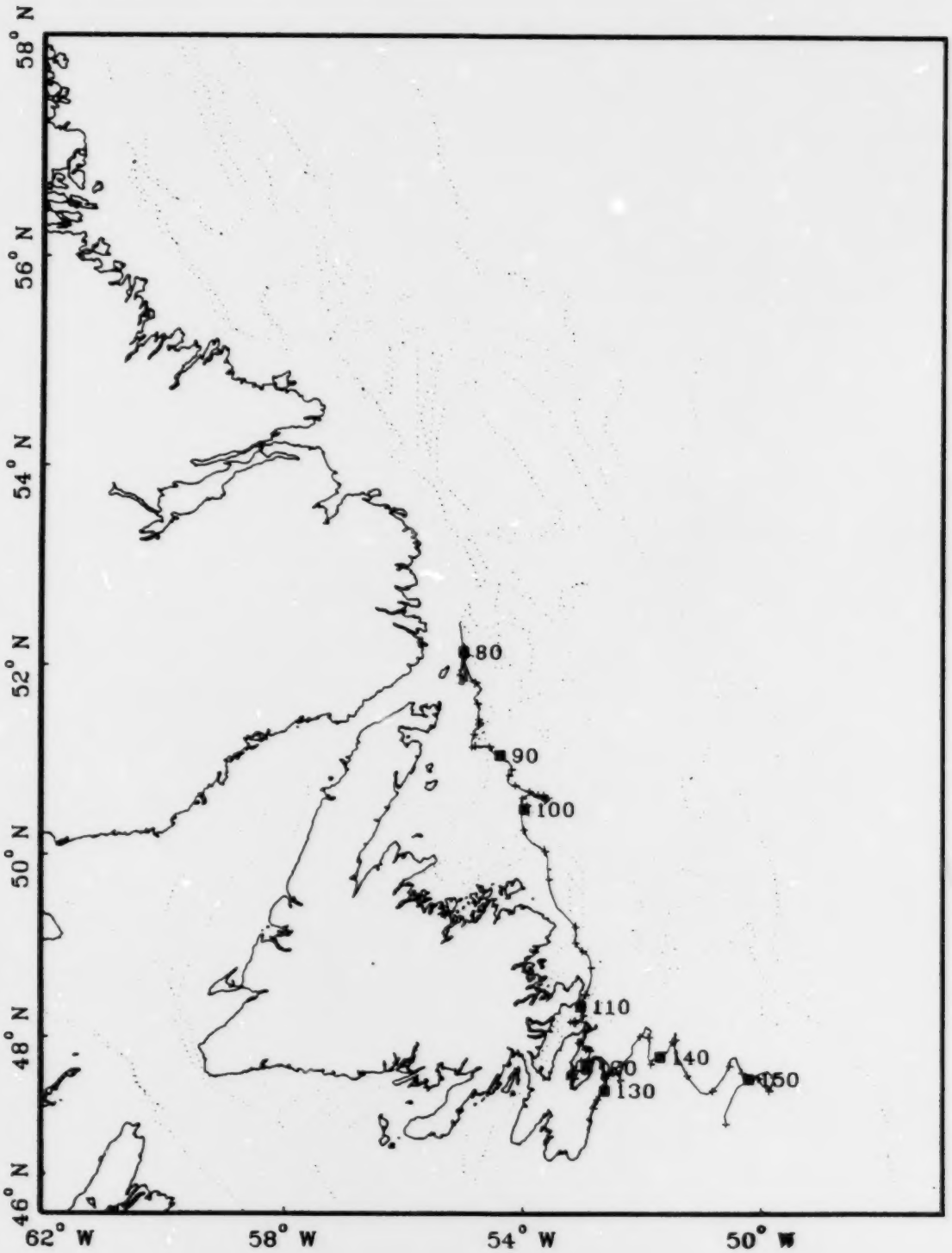
BUOY 2376 – 1991



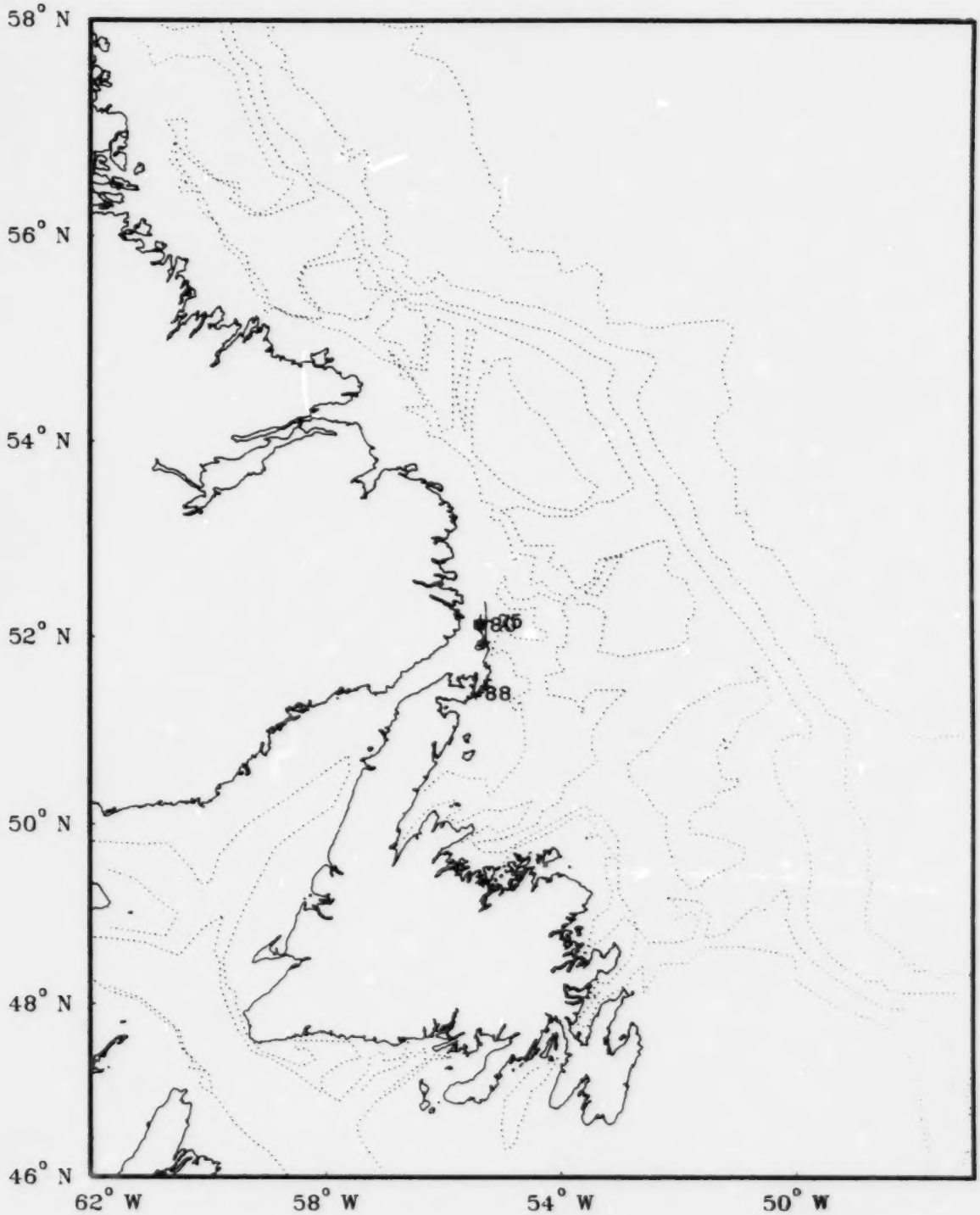
BUOY 2377 – 1991



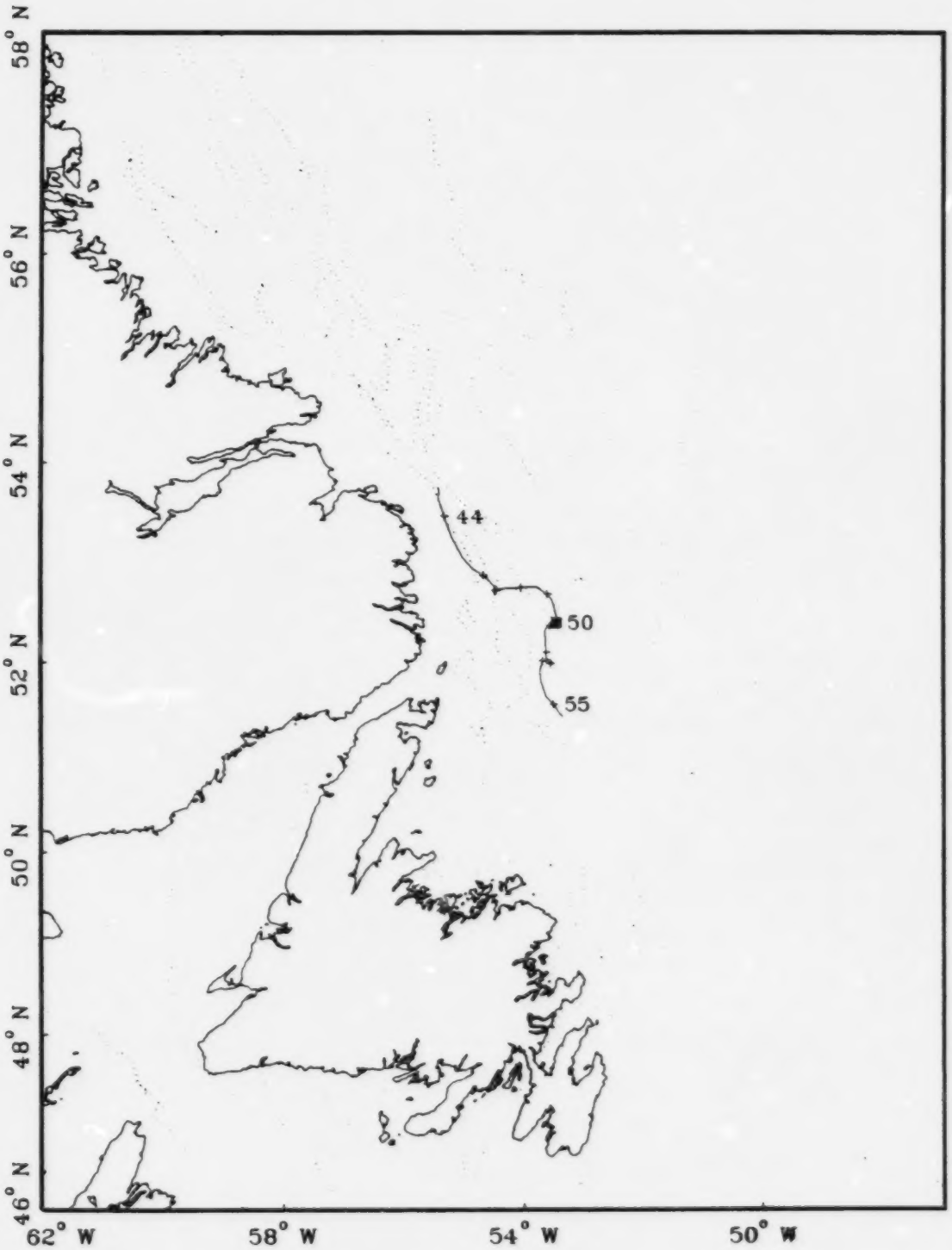
BUOY 3319 – 1991



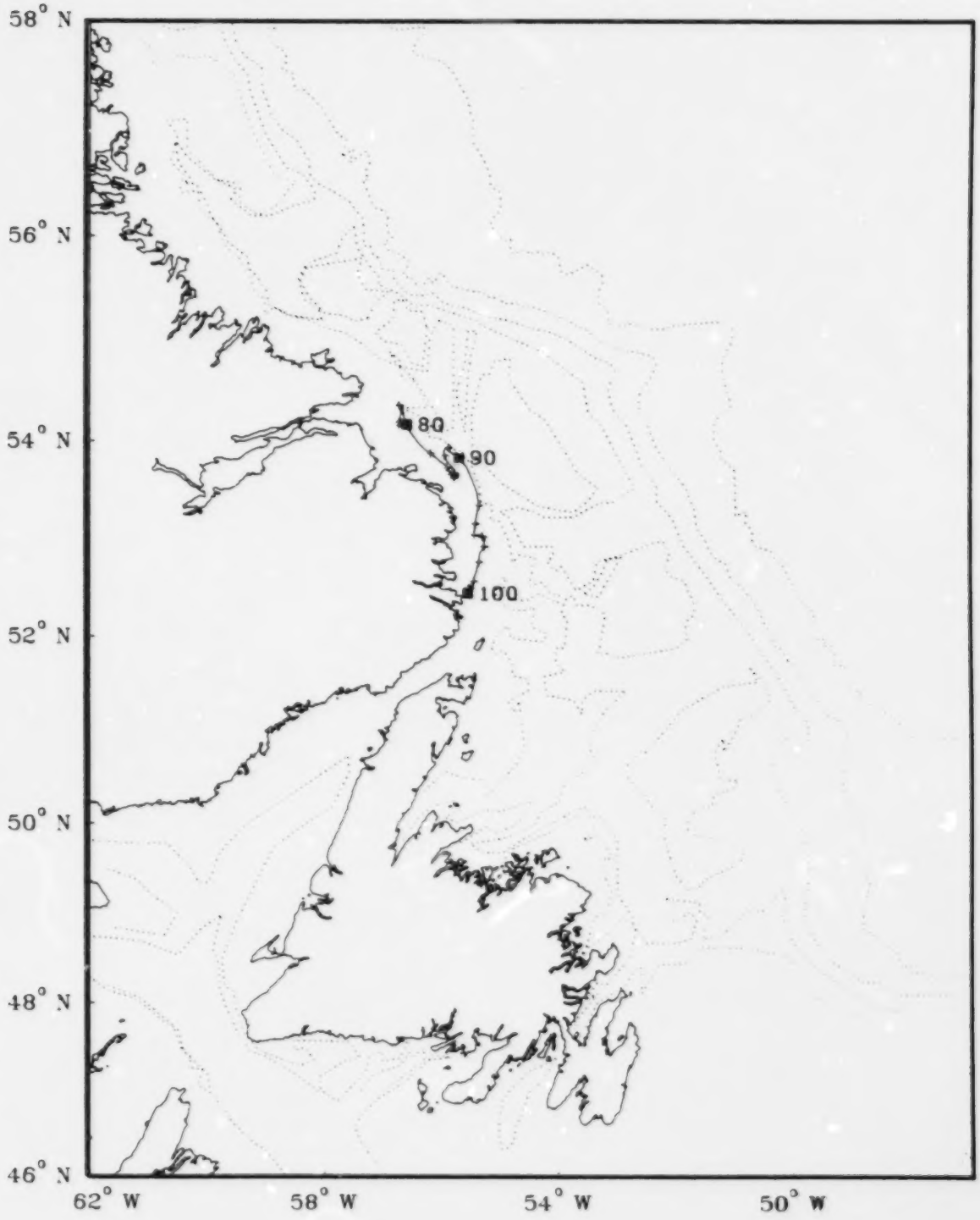
BUOY 3320 – 1991



BUOY 4761 – 1991



BUOY 4762 – 1991



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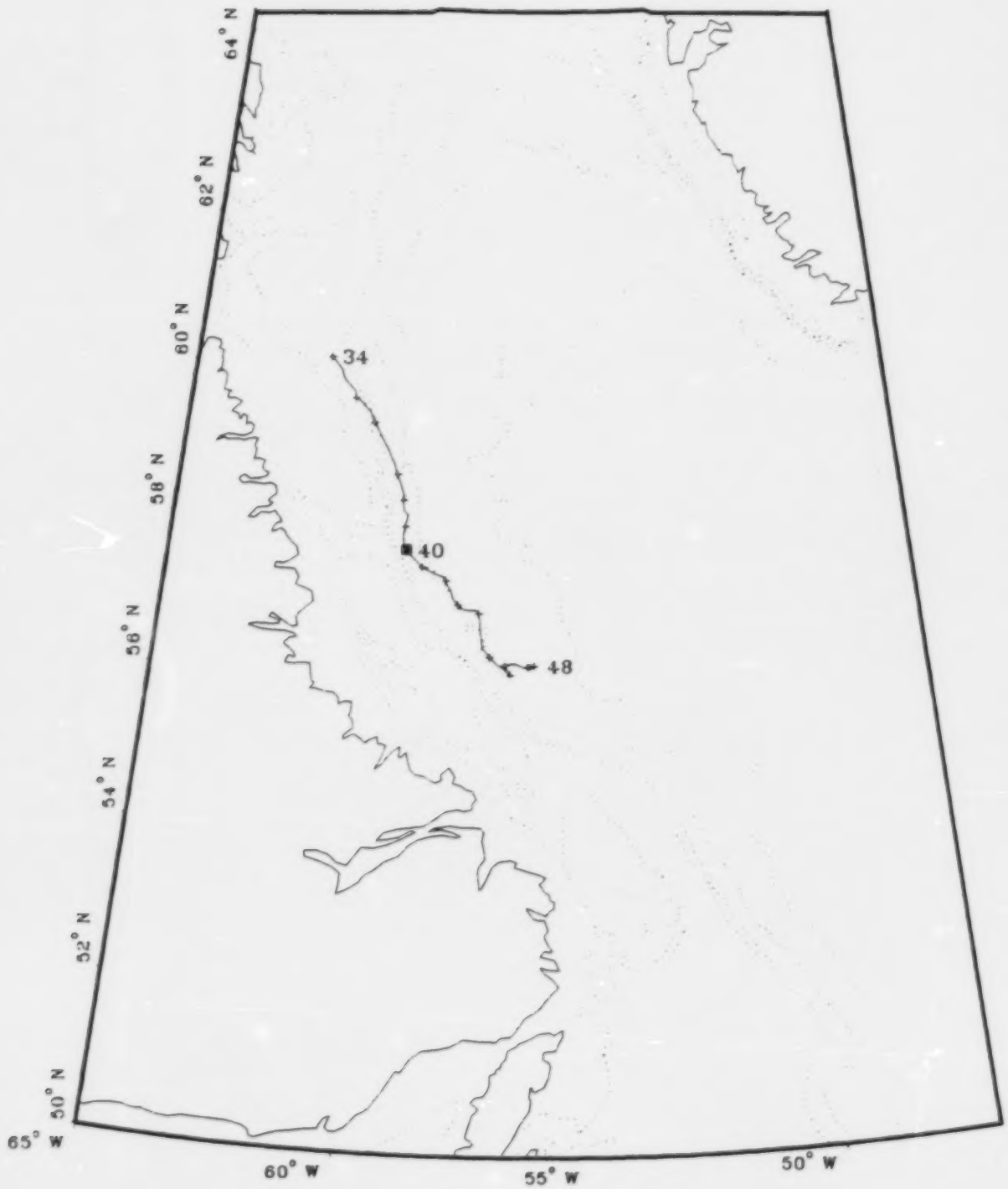
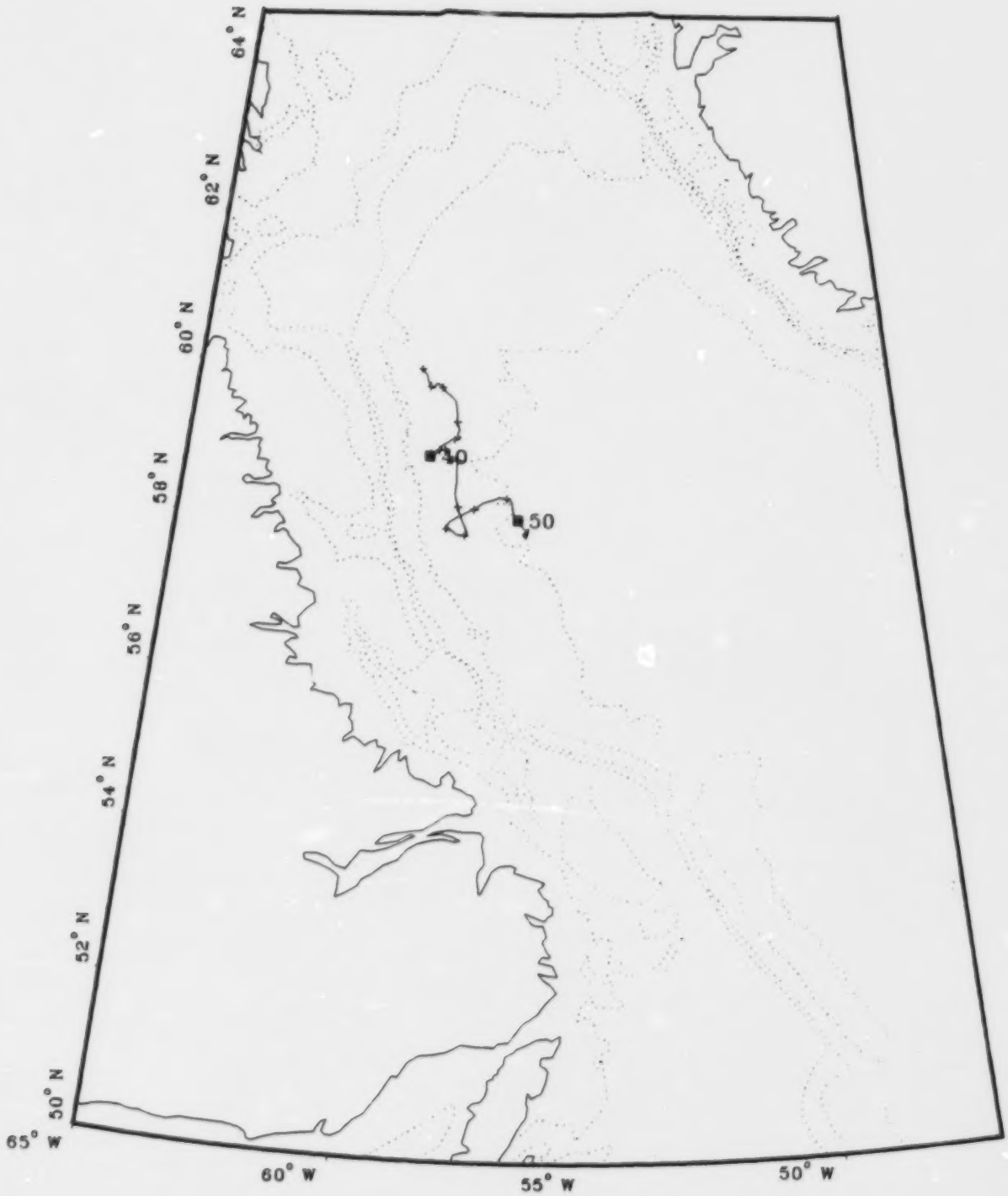


BUOY 5216 – 1991



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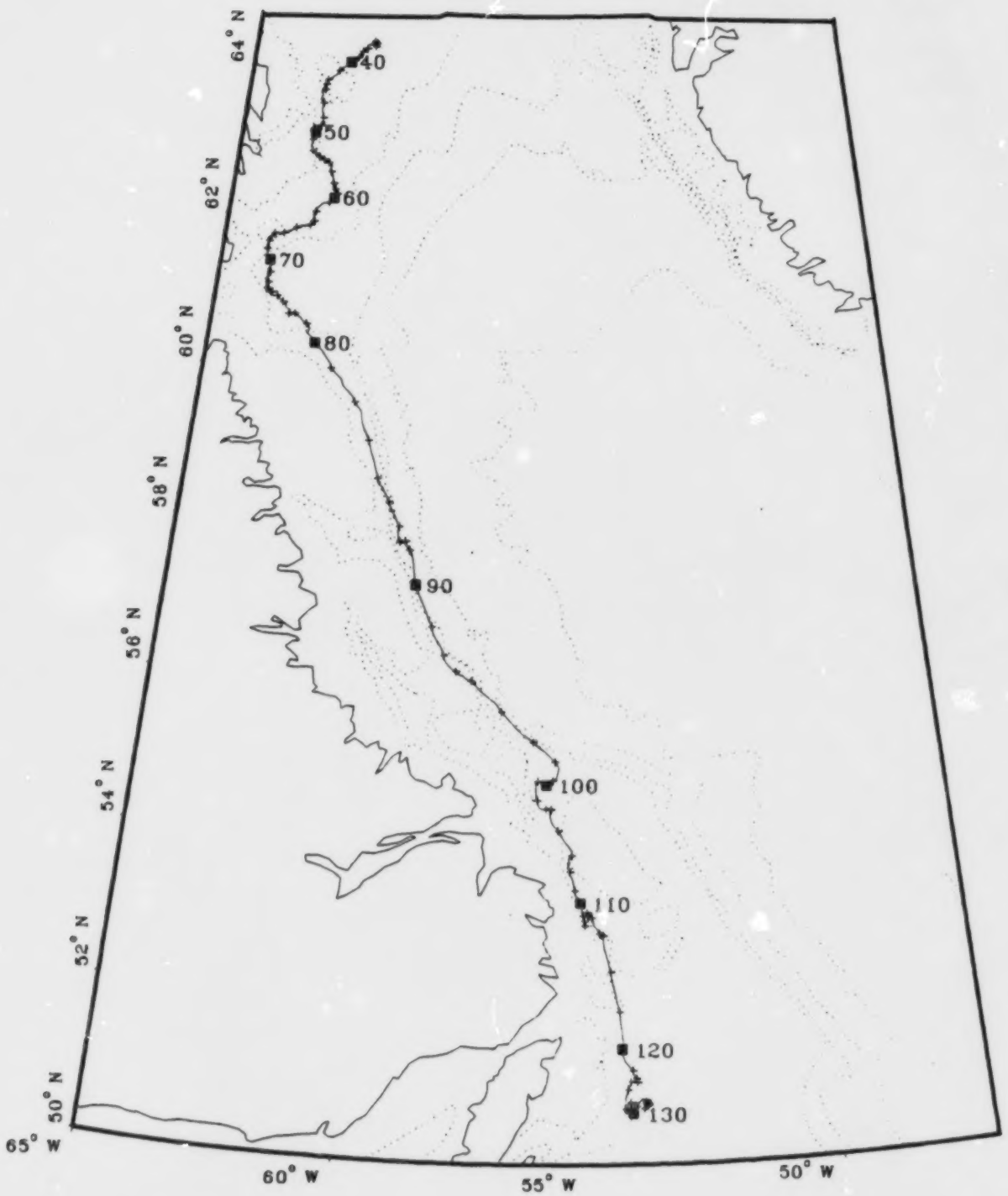

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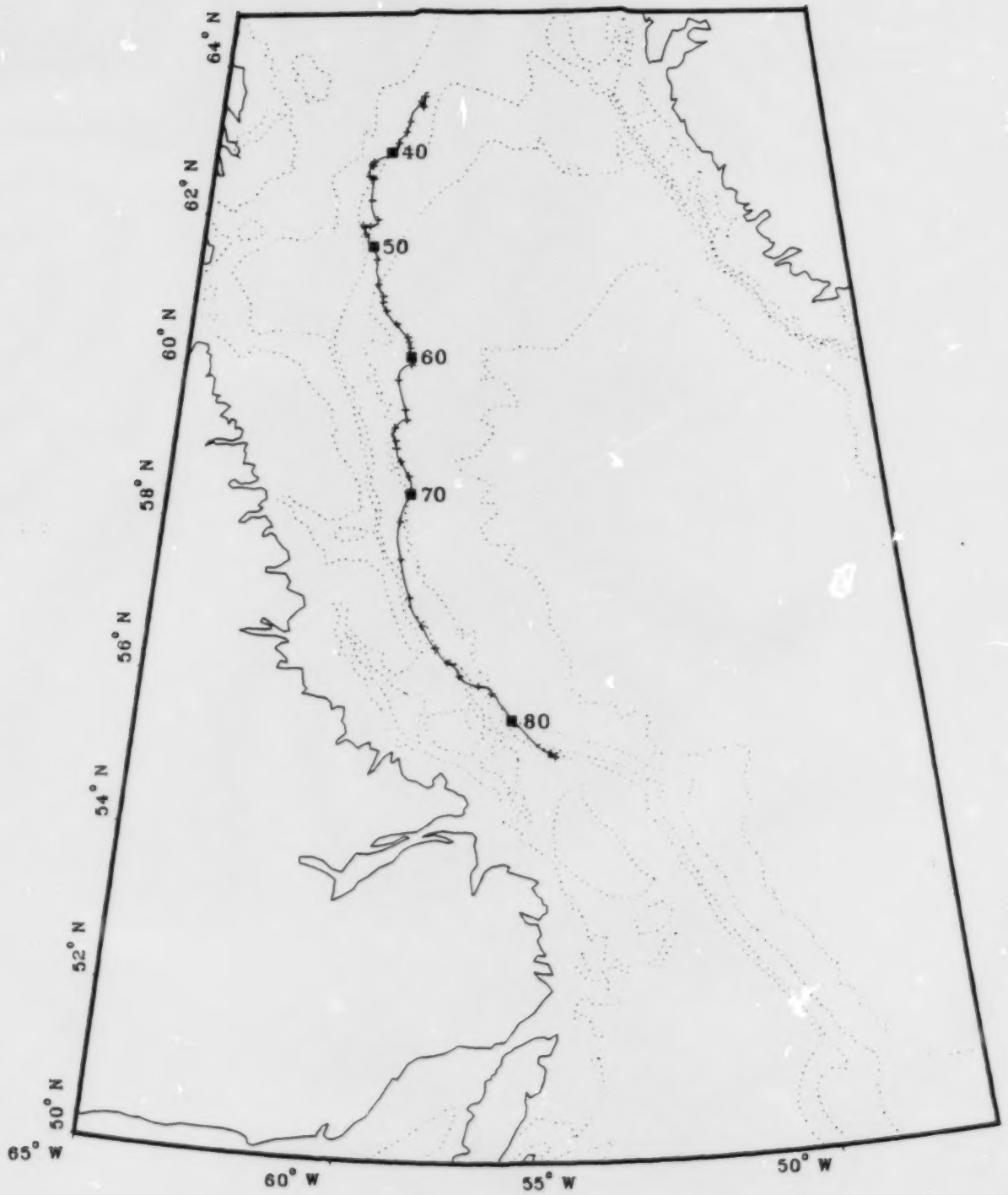
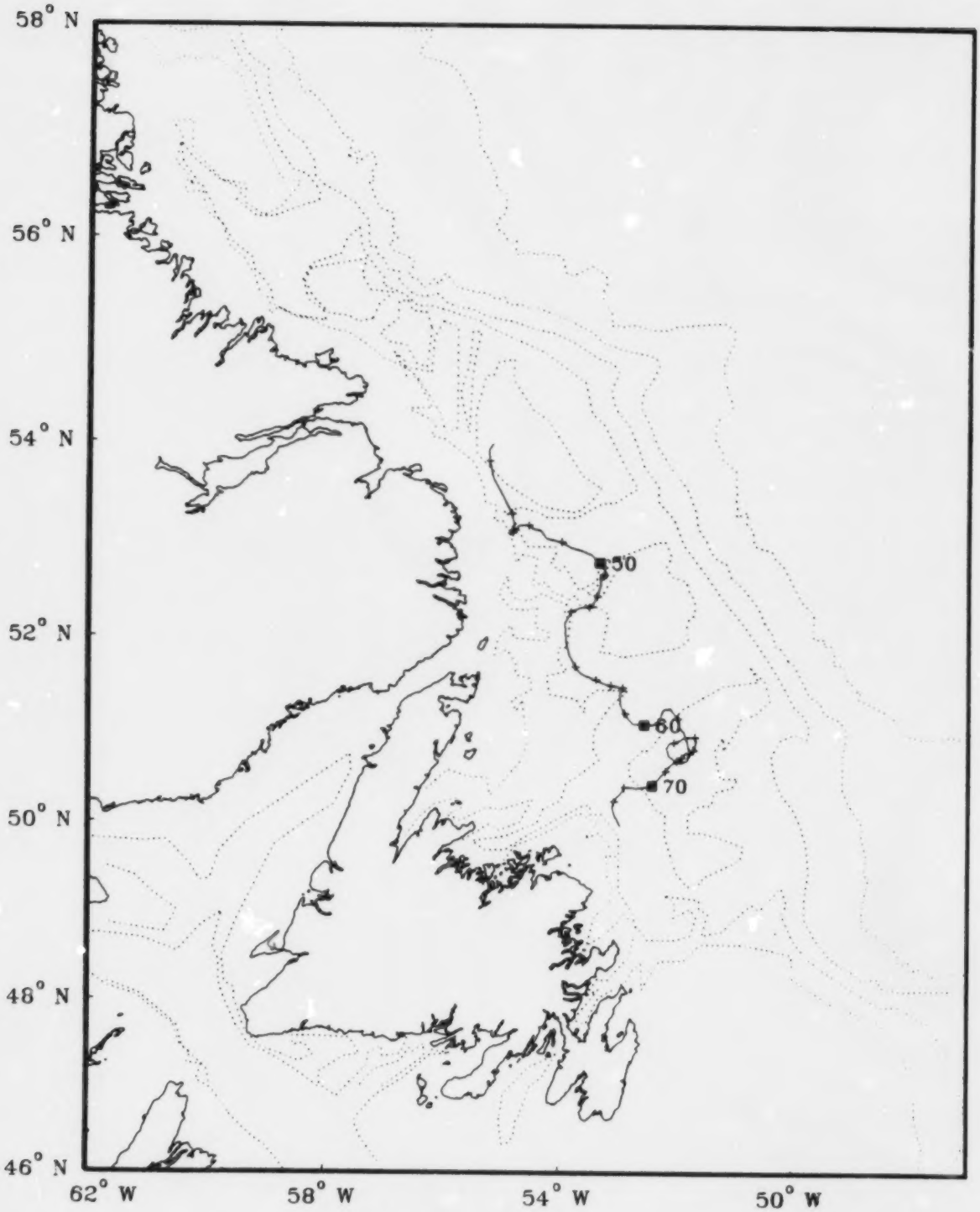


BUOY 5437 – 1991



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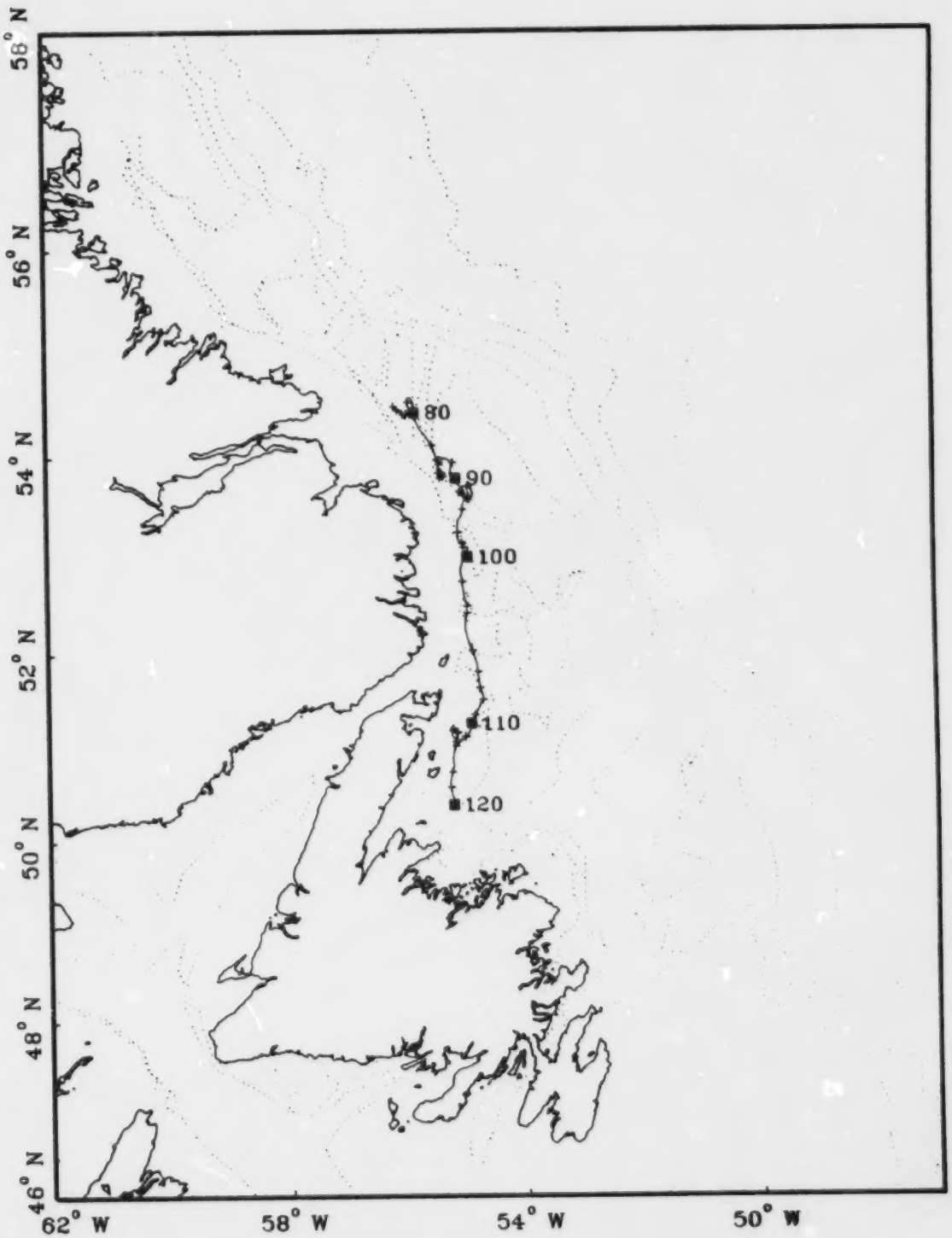
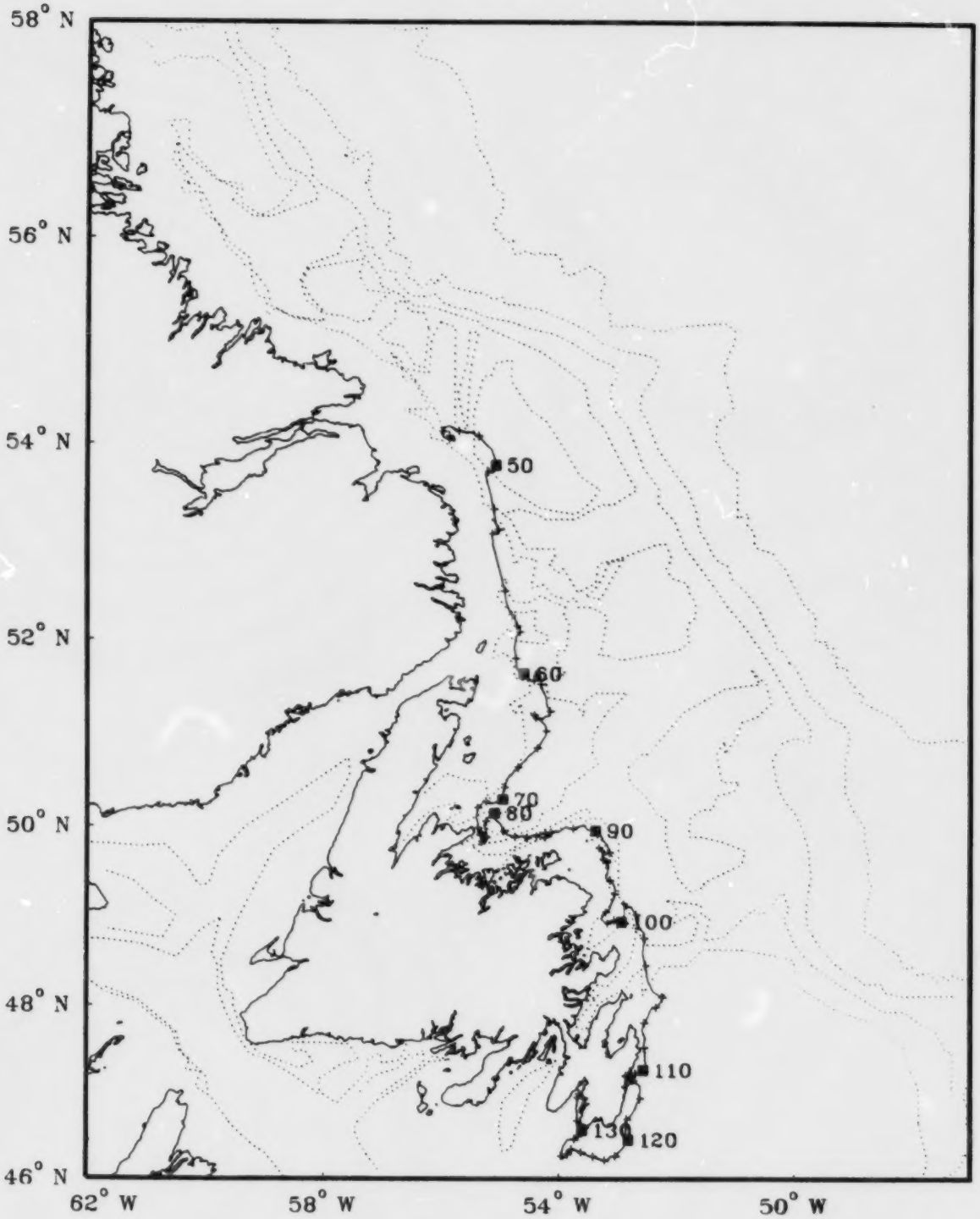


BUOY 8666 – 1991



APPENDIX C: ICE BEACON ENVIRONMENTAL DATA

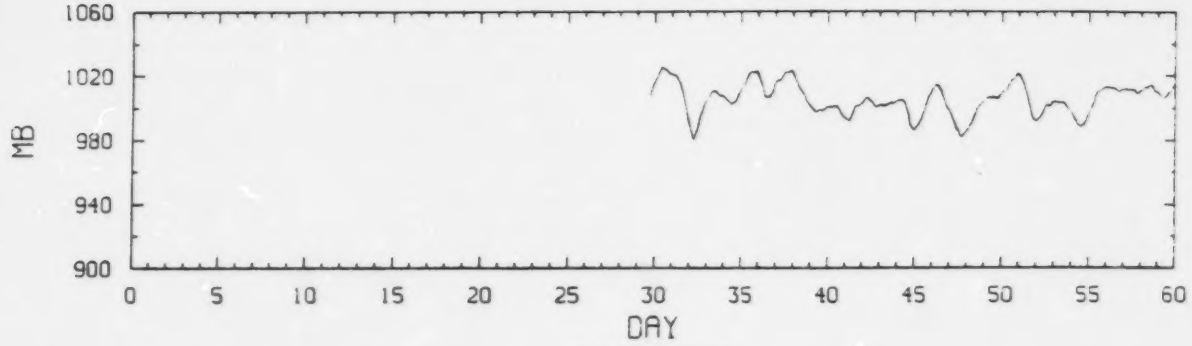
Time series plots of the environmental data collected by the beacons deployed on the mobile pack ice and the land-fast ice in Cartwright harbour.

Beacon ID #	Start Time*	End Time*	Type	Location
1052	29	82	Ice staff (SIMP)	Cartwright
1055	74	108	Ice staff (SIMP)	Pack ice
2393	9	135	Ice staff (IMP)	Cartwright
3319	74	151+	Location+	Pack ice
3320	74	89	Location+	Pack ice
4761	43	56	Location (CMIB)	Pack ice
4762	75	101	Location (CMIB)	Pack ice
5437	43	73	Ice staff (IMP)	Pack ice
8648	75	120	Anemometer	Pack ice
8666	45	151+	Anemometer	Pack ice

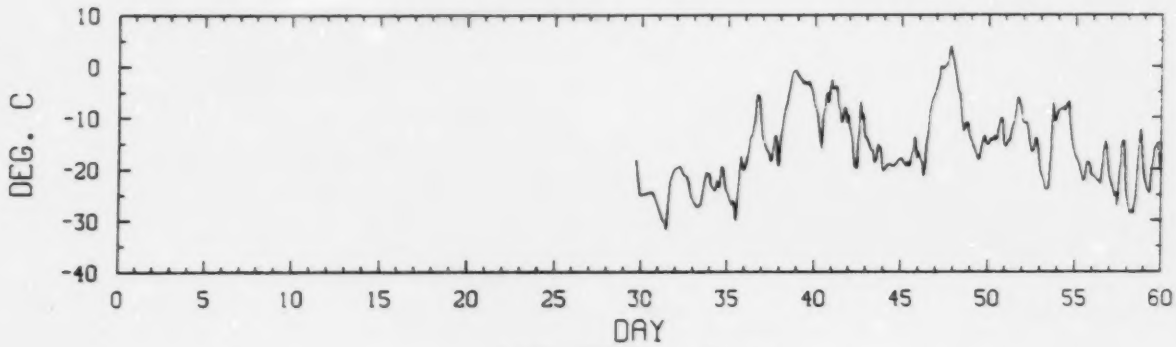
* times in 1991 calendar days.

BUOY 1052 - 1991

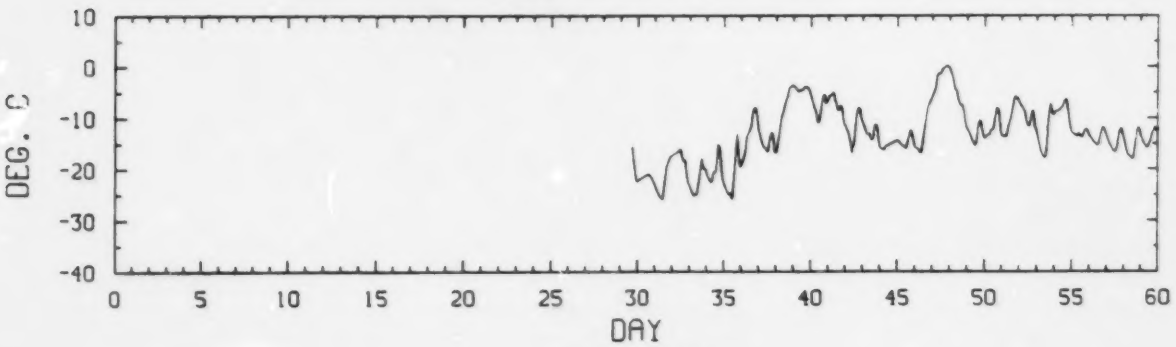
PRESSURE



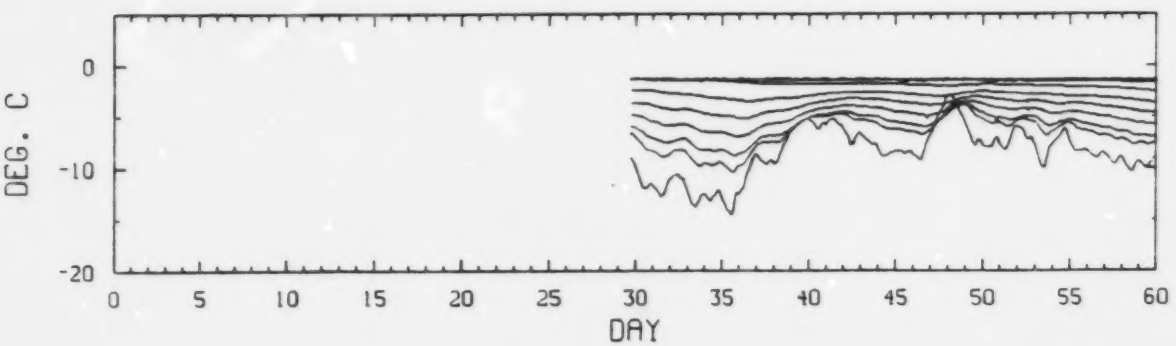
AIR TEMP



ICE TEMP (0 M)

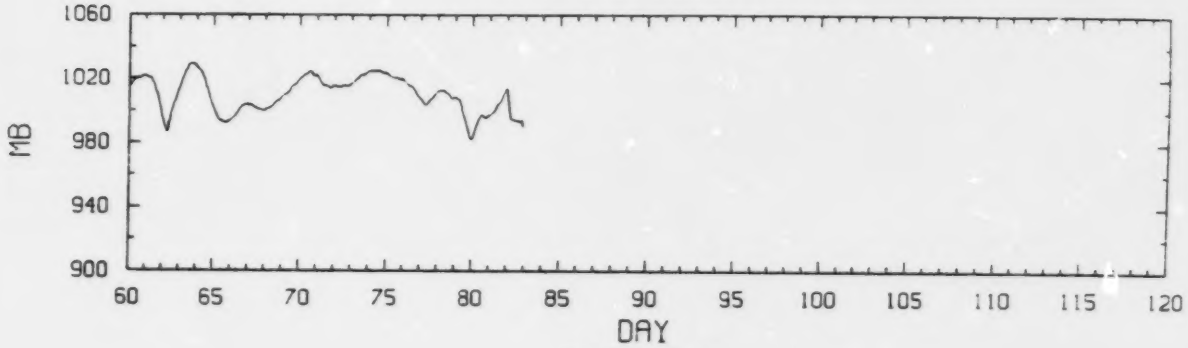


ICE TEMP



BUOY 1052 - 1991

PRESSURE



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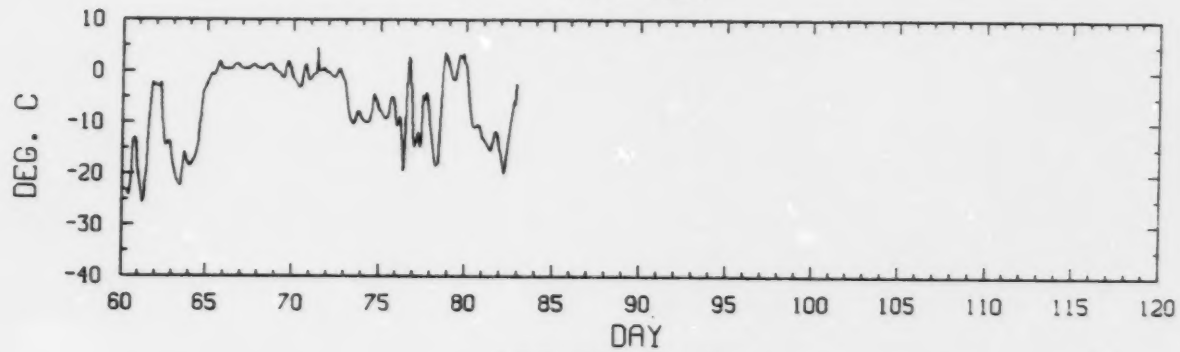

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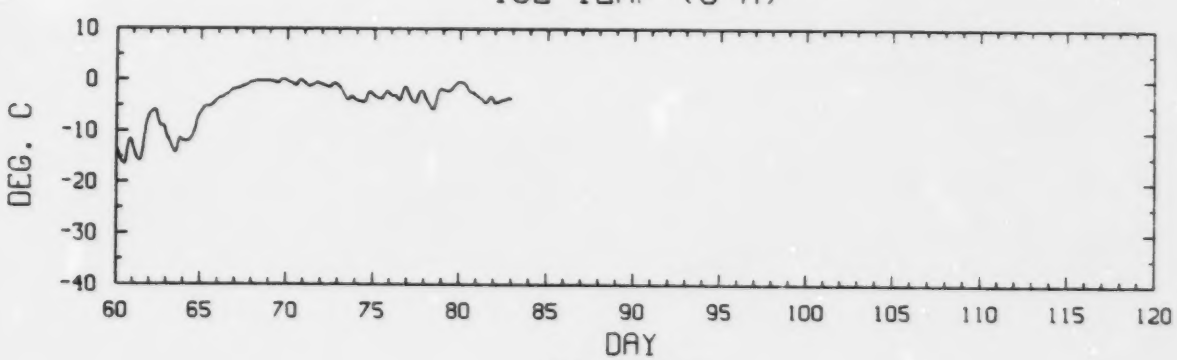

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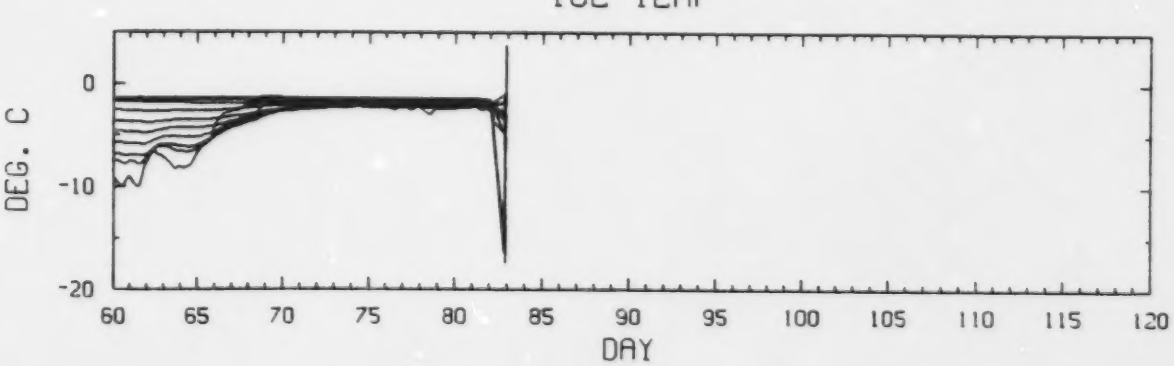
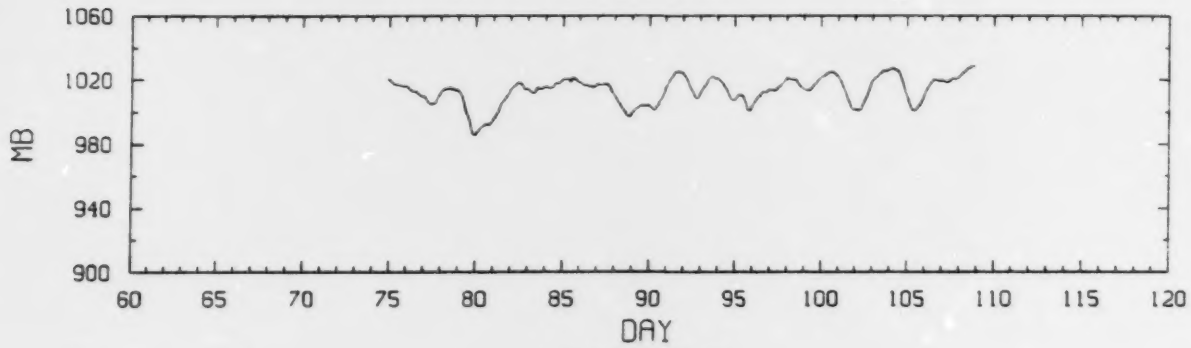
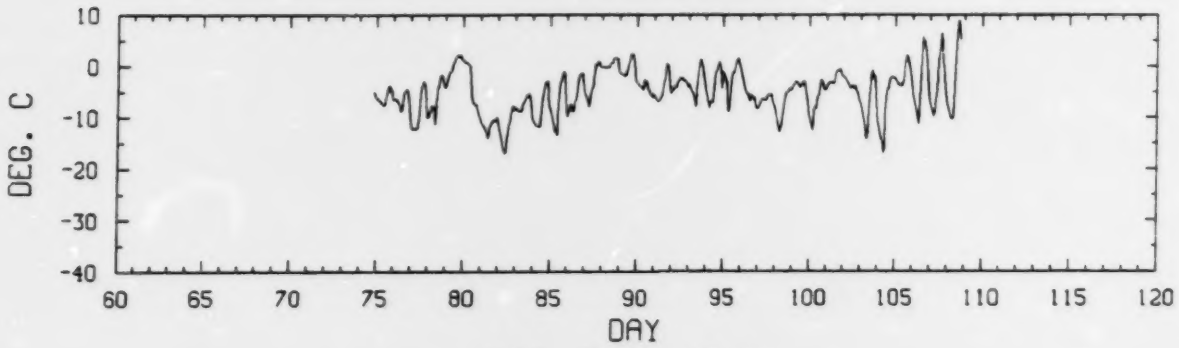


BUOY 1055 - 1991

PRESSURE



AIR TEMP



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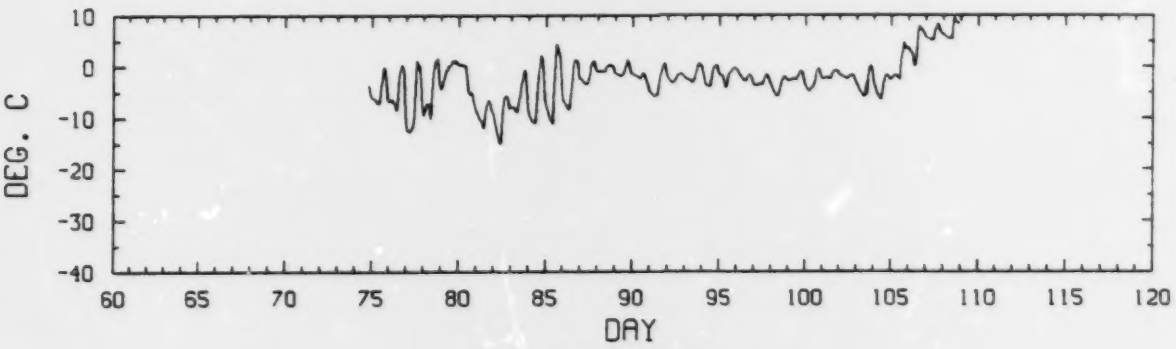

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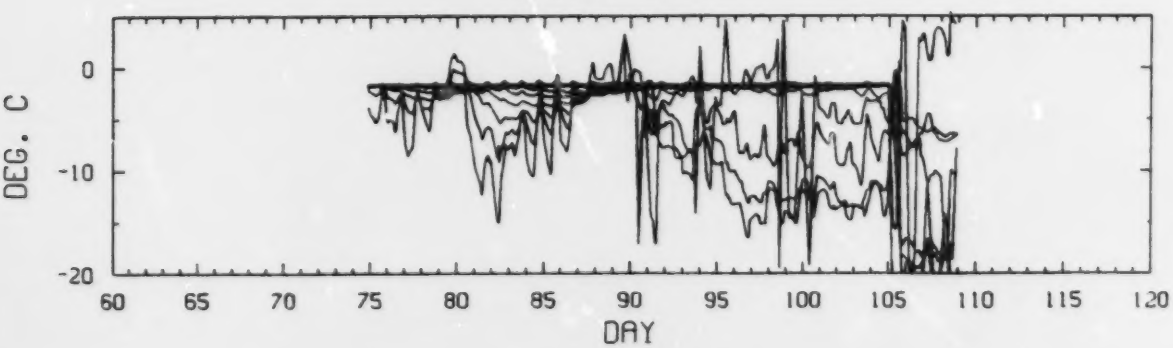
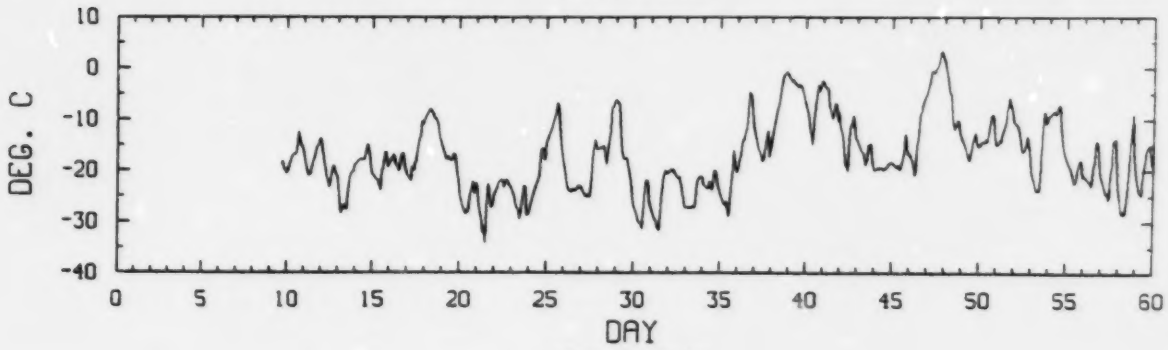


BUOY 2393 - 1991

AIR TEMP



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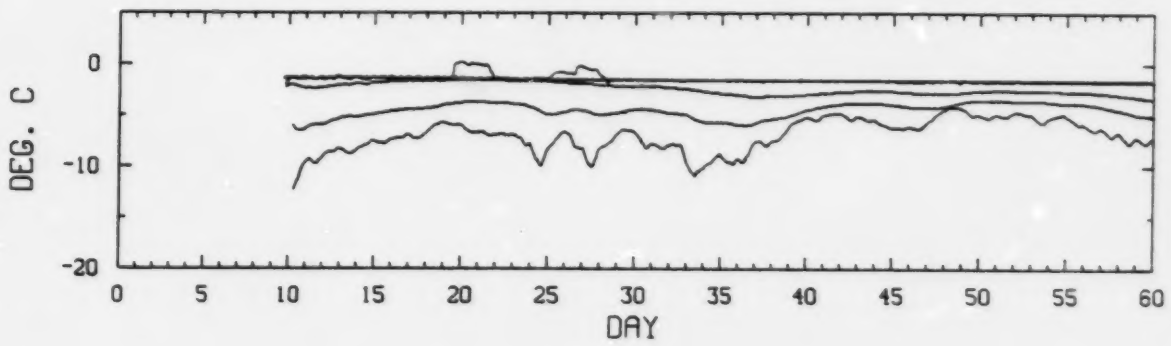

BUOY 2393 - 1991

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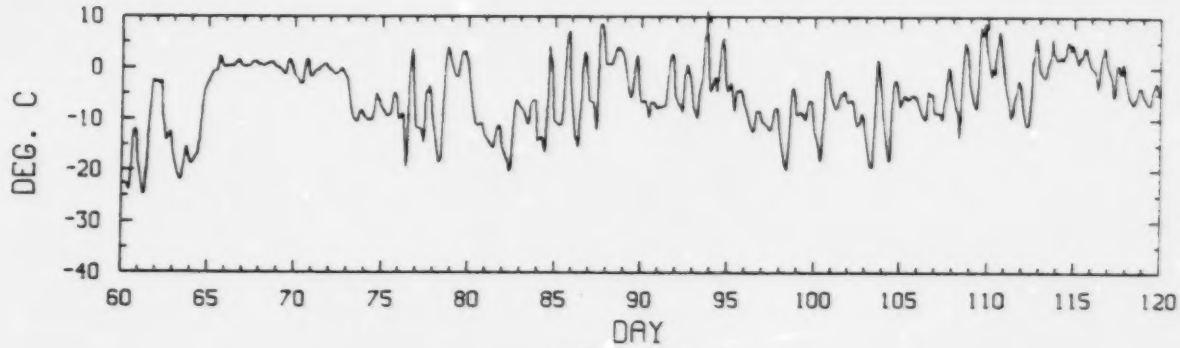

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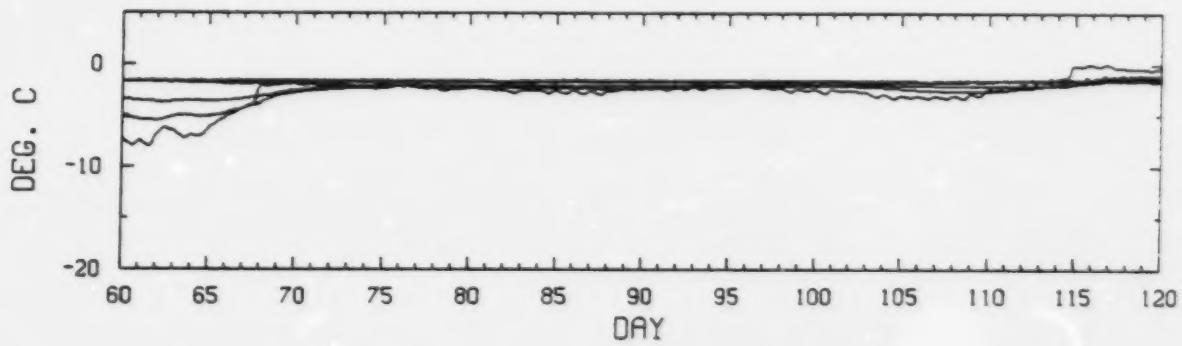

BUOY 2393 - 1991

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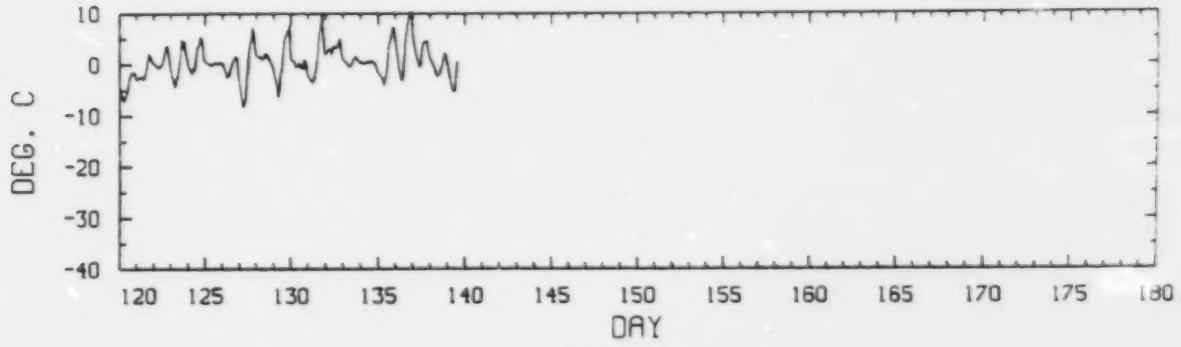

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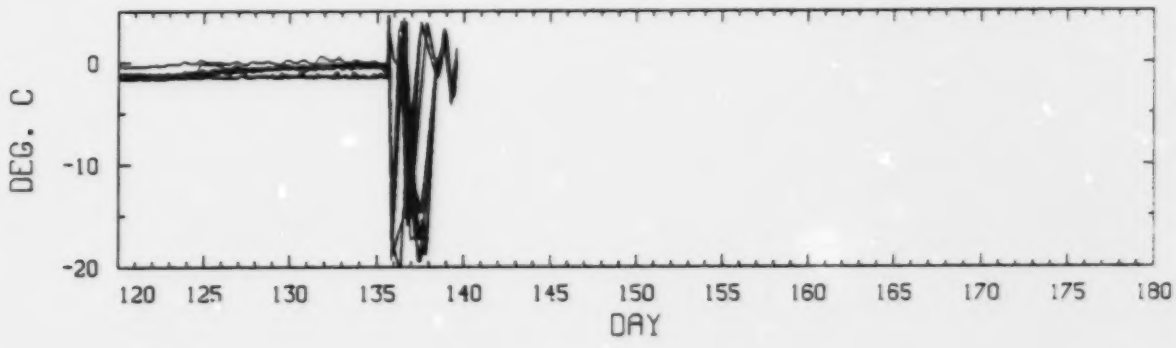

BUOY 3319 - 1991

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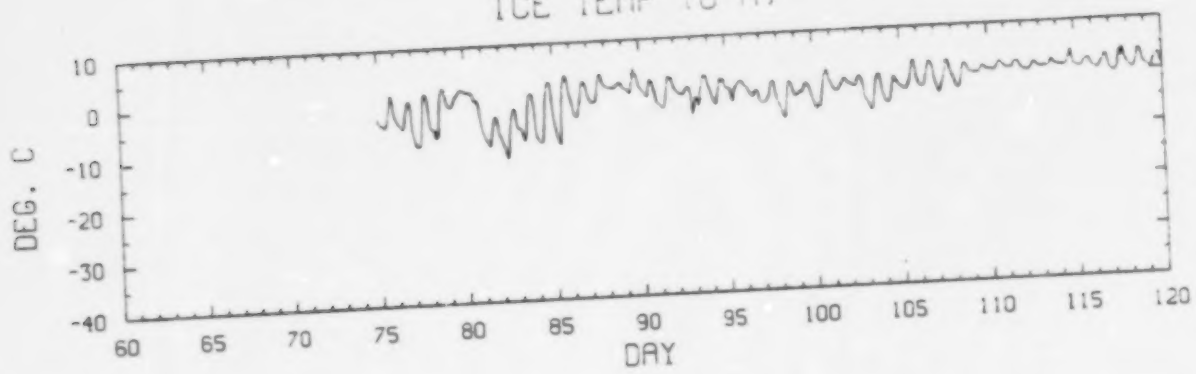

BUOY 3319 - 1991

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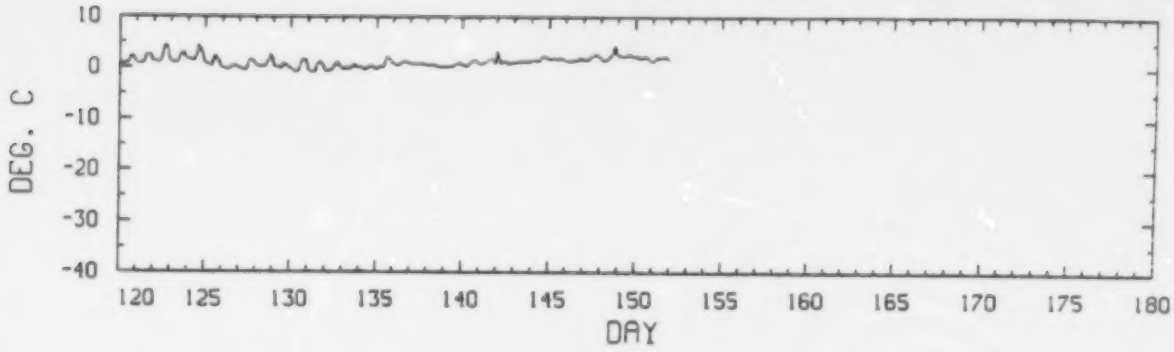

BUOY 3320 - 1991

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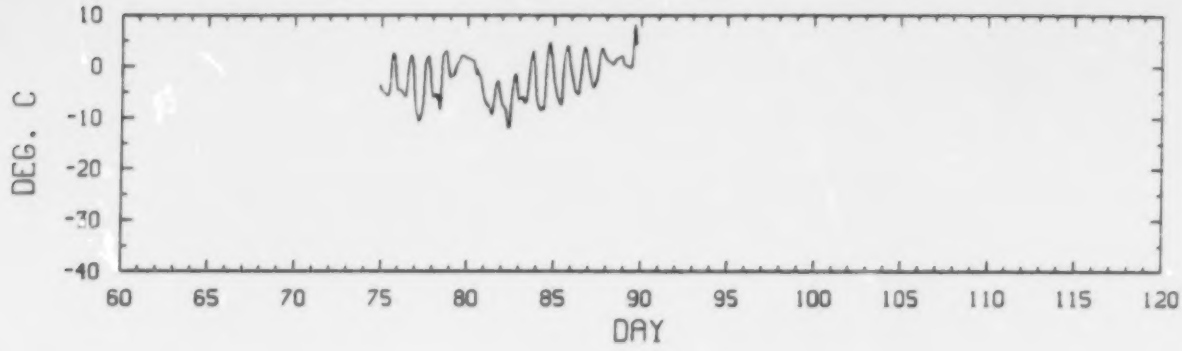
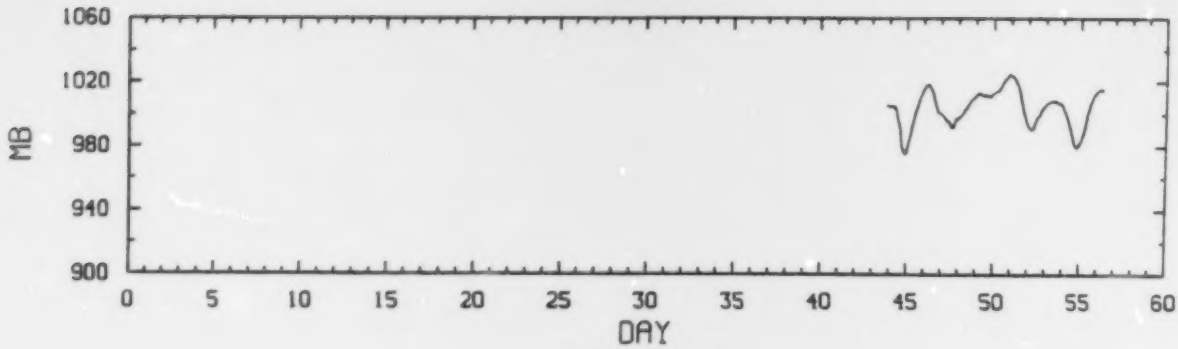


BUOY 4761 - 1991

PRESSURE



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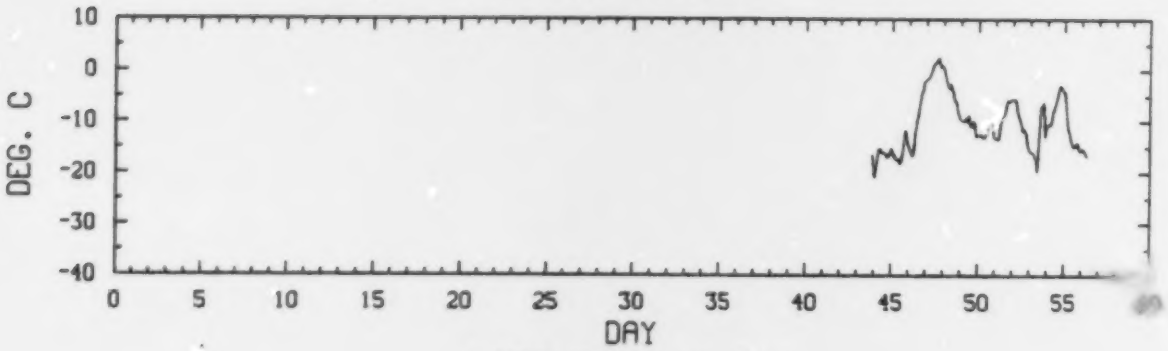

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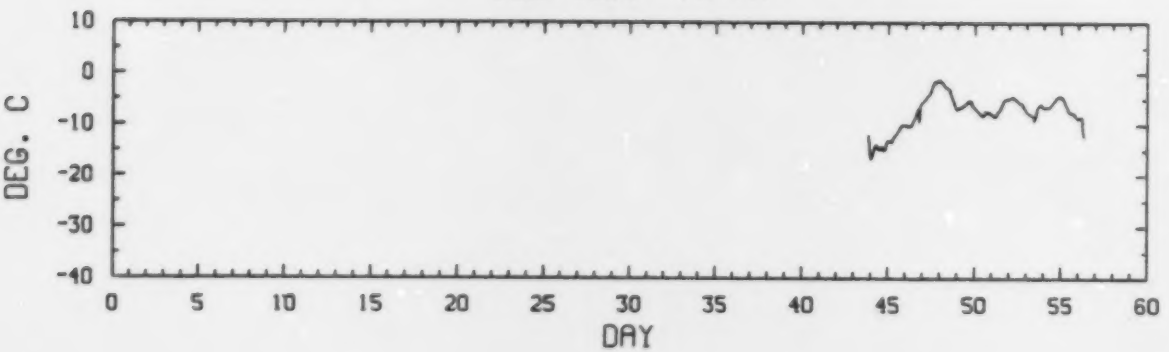

BUOY 4762 - 1991

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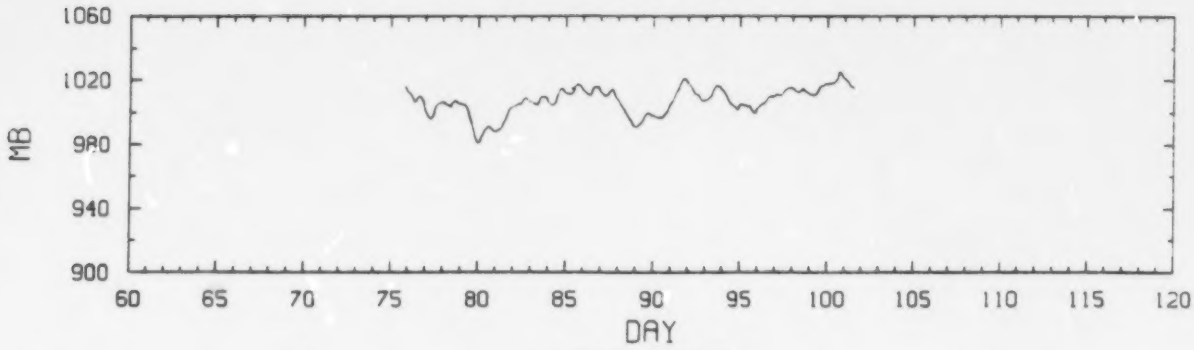

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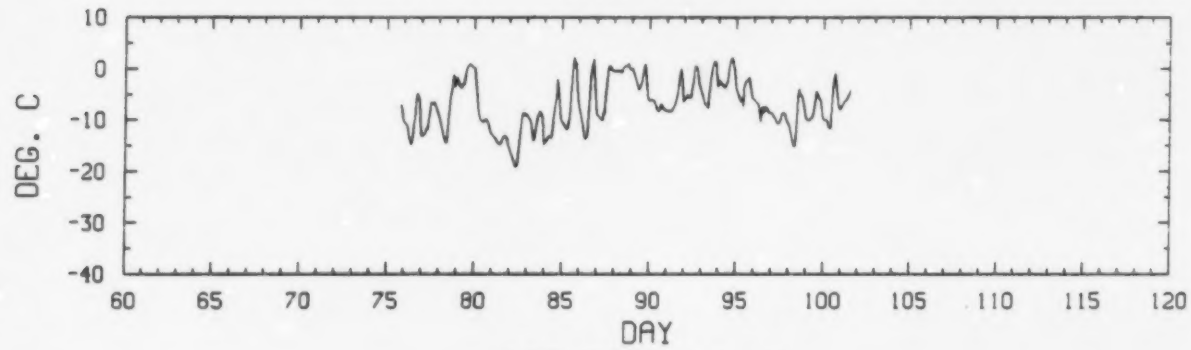

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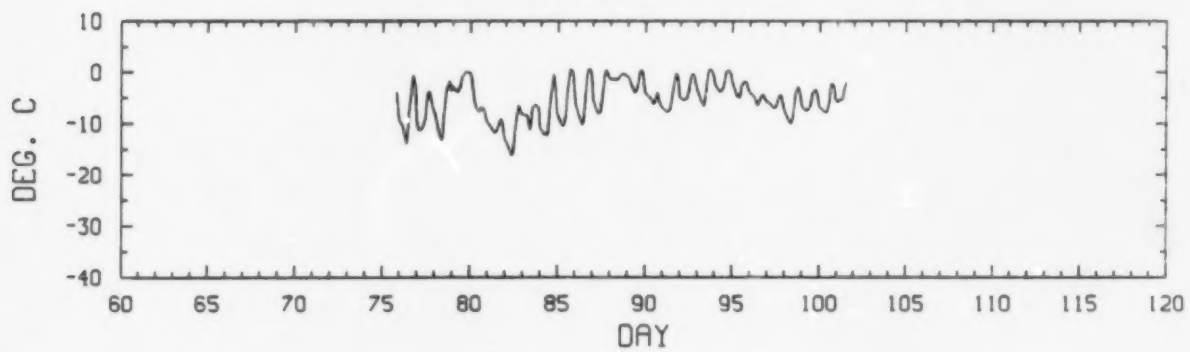

BUOY 5437 - 1991

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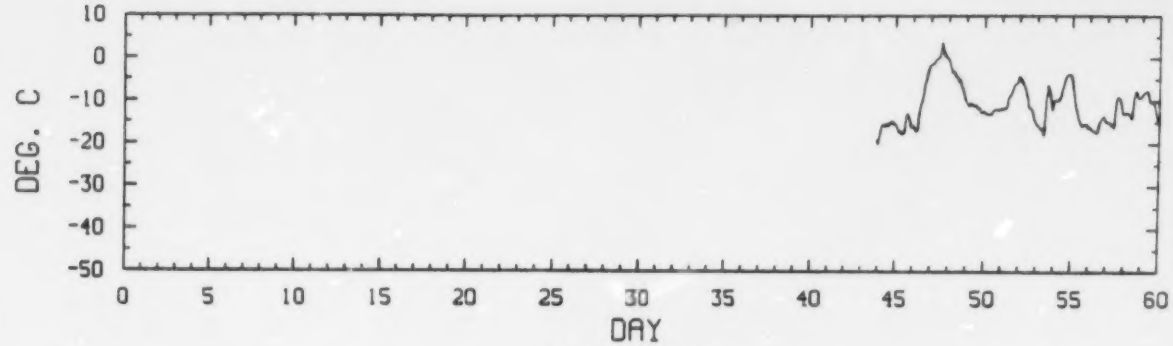

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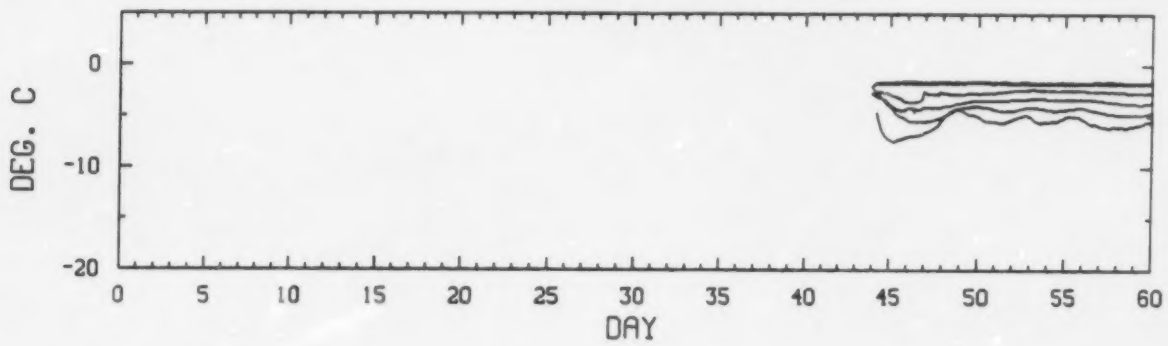

BUOY 5437 - 1991

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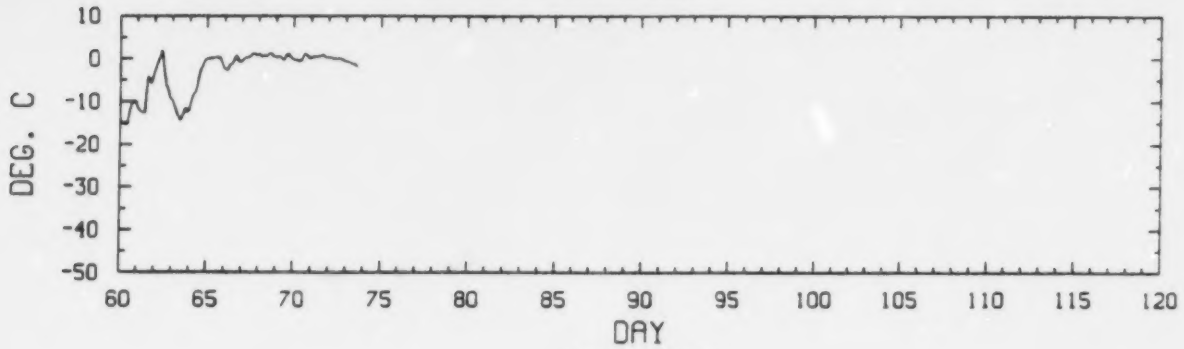

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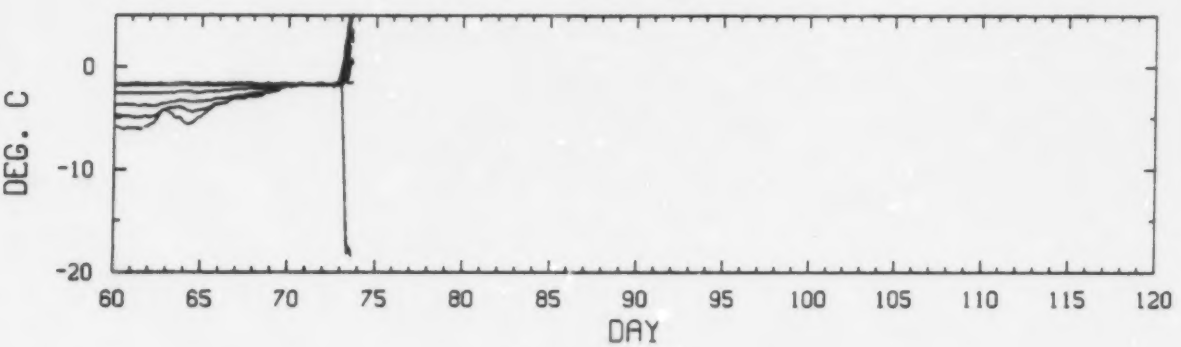

BUOY 8648 - 1991

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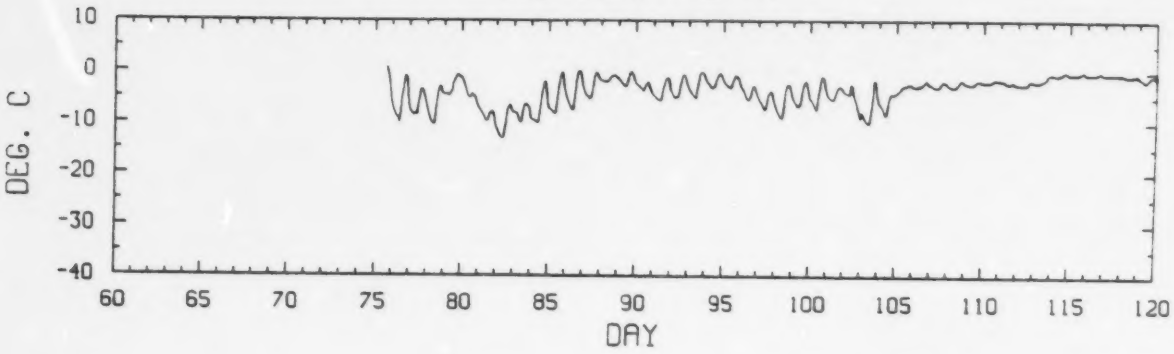

BUOY 8648 - 1991

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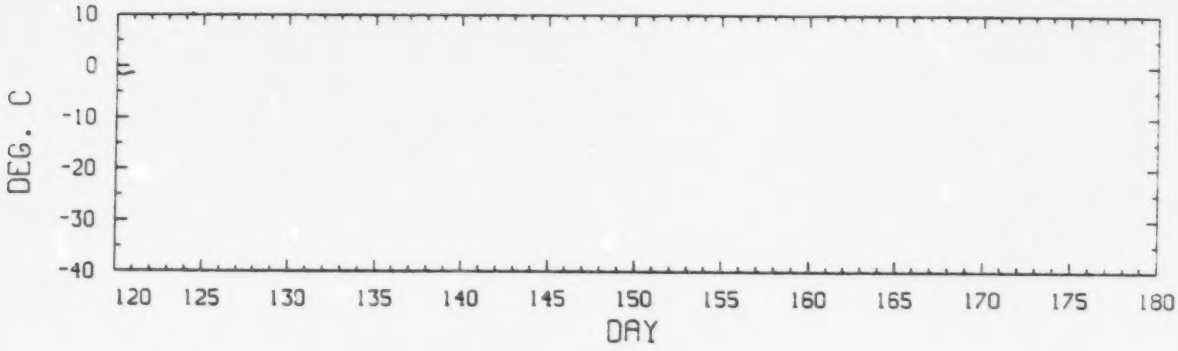
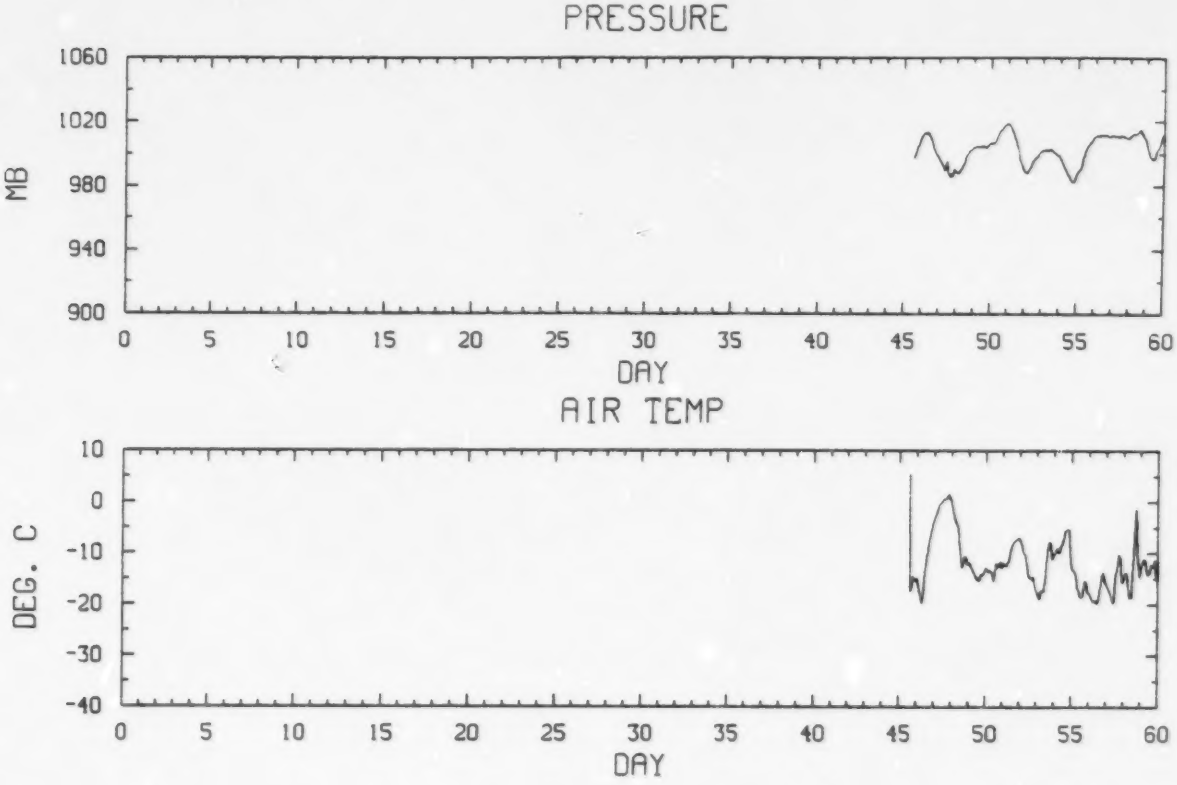
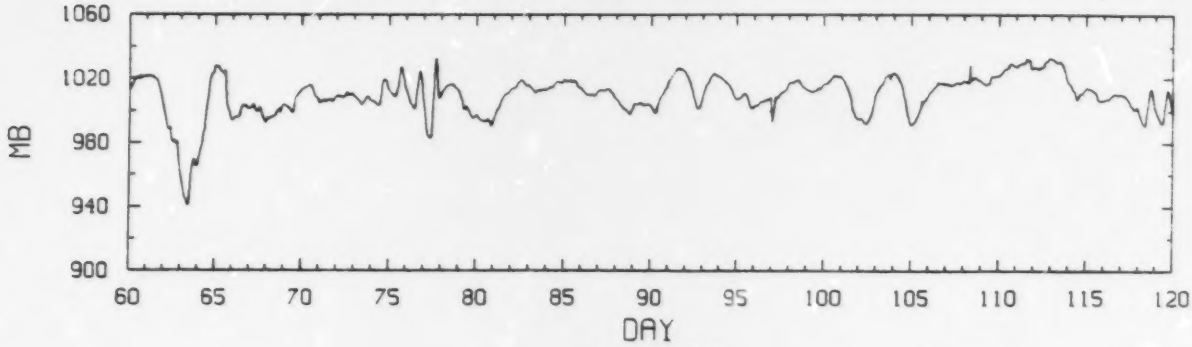


BUOY 8666 - 1991

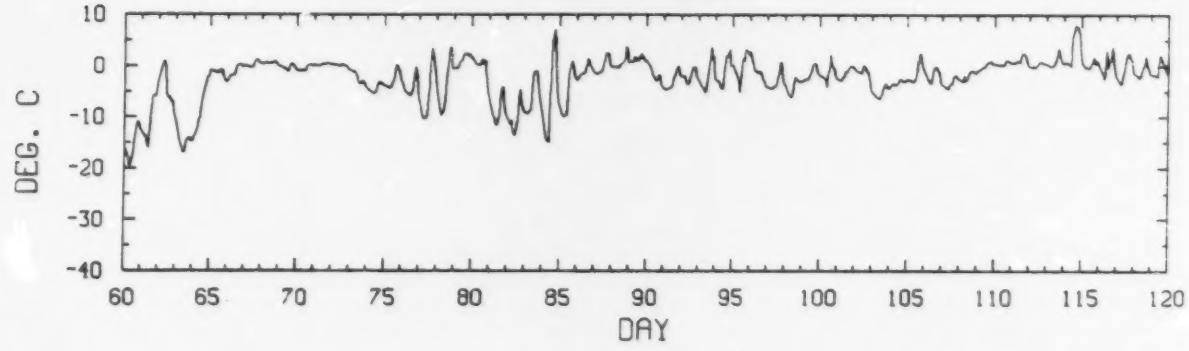


BUOY 8666 - 1991

PRESSURE

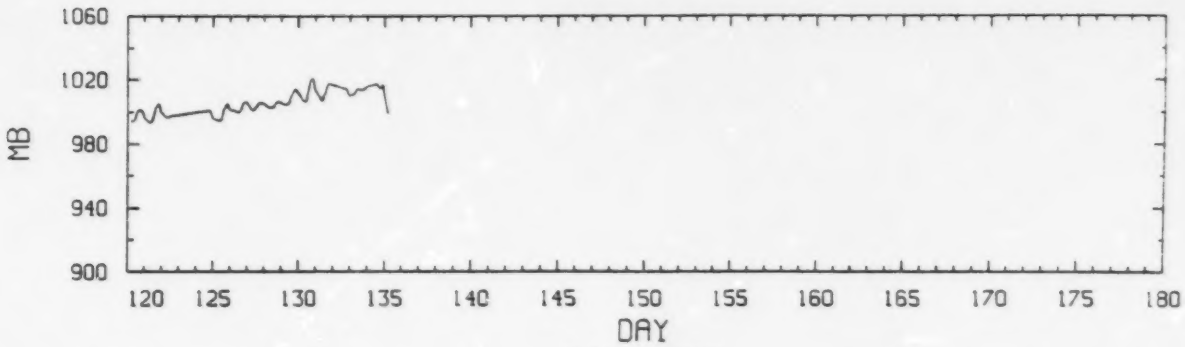


AIR TEMP

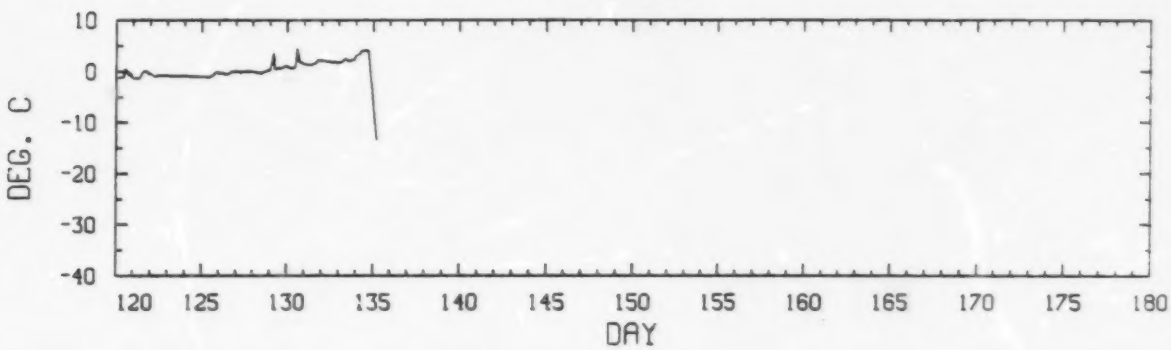


BUOY 8666 - 1991

PRESSURE



AIR TEMP



APPENDIX D: ICE AND SURFACE WATER SALINITY SAMPLES

Stn. 9101 Location: Cartwright harbour (5 visits)

Depth 5.0m
Lat. 53.700 °N
Long. 57.020 °W

1. January 9 : Ice 48 and 48cm
Snow 6 and 5cm

Sample#	Depth cm	Bottle #	Salinity ppt
9101.01	0 - 10	46101	14.047
9101.02	10 - 20	46102	10.599
9101.03	20 - 30	46103	9.601
9101.04	30 - 40	46104	7.811
9101.05	Sea W.	46105	27.545

2. February 12: Ice 60, 64 and 57cm
Snow 24, 21 and 26cm

Sample#	Depth cm	Bottle #	Salinity ppt
9101.06w	10 - 15	64622	22.065
9101.07w	30 - 35	64623	9.267
9101.08w	50 - 55	64624	12.029

3. February 14: Ice and snow as above

Sample#	Depth cm	Bottle #	Salinity ppt
9101.09w	10 - 15	64625	8.563
9101.10w	20 - 25	64626	5.902
9101.11w	30 - 35	64627	6.221
9101.12w	45 - 50	64628	9.455
9101.13	Sea W.	64629	28.426

4. March 16 : Ice 90, 90 and 90cm (of which 22cm is refrozen snow)
Snow 4, 4 and 5cm
Freeboard 10cm to lose snow /ice interface

Sample#	Depth cm	Bottle #	Salinity ppt
9101.14w	32 - 37	64639	12.747
9101.15	Sea W.	64661	29.326

5. May 15 : Ice 78, 77 and 78cm (all refrozen snow melted)
Snow 0, 0 and 0cm
Freeboard 7, 8 and 11cm

Sample#	Depth cm	Bottle #	Salinity ppt
9101.16	Melt W.	73533	1.269
9101.17w	15 - 20	73534	0.337
9101.18w	30 - 40	73535	0.642
9101.19w	55 - 60	73538	1.046
9101.20w	65 - 75	73542	1.234
9101.21	Sea W.	73536	23.150

Station 9102

Location: 58 miles east of Black Tickle — Lat. 54.220°N
Location beacon #2376 — Long. 54.850°W
CTD Stn. File CWFEB00.DAT — (ARGOS loc.)

Time: February 12, 1991 — Day 43, 1800GMT
Ice: 95, 104 and 117cm — Floe size .2x.2 km
Snow: 1, 1 and 1cm — 10/10 ice conc.

Sample#	Depth cm	Bottle #	Salinity ppt
9102.01	15 - 20	64616	11.897
9102.02	40 - 45	64617	18.156
9102.03	Sea W.	64615	32.004

Station 9103

Location: 40 miles east of Black Tickle — Lat. 54.011°N
Large IMP beacon #5437 — Long. 55.120°W
CTD Stn. File CWFEB01.DAT — (ARGOS loc.)

Time: February 12, 1991 — Day 43, 1900GMT
Ice: 71, 65 and 68cm — Floe size 1x1 km
Snow: 4, 4.5 and 4cm — 9/10 ice conc.

Sample#	Depth cm	Bottle #	Salinity ppt
9103.01	10 - 15	64618	19.289*
9103.02	20 - 25	64619	33.108*
9103.03	30 - 35	64620	38.464*
9103.04	Sea W.	64621	32.620

* Possible evaporation loses due to ice chips in bottle cap?

Station 9104

Location: 25 miles east of Black Tickle — Lat. 53.764 °N
Small location beacon #4761 — Long. 55.425 °W
No CTD (too late) — (ARGOS loc.)

Time: February 12, 1991 — Day 43, 1930GMT
Ice: 42, 45 and 43cm — Floe size .1x.1 km
Snow: 5, 4 and 4.5cm — 9/10 ice conc.

Station 9105

Location: 50 miles east of Gannet Island — Lat. 54.206 °N
Large location beacon #2377 — Long. 55.829 °W
No CTD (too cold and windy) — (ARGOS Loc.)

Time: February 14, 1991 — Day 45, 1400GMT
Ice: 55, 75 and 85cm — Visibility 10m
Snow: 20, 15 and 18cm — Snowing

Station 9106

Location: 35 miles east of Gannet Island — Lat. 54.066 °N
Anemometer beacon #8666 — Long. 55.960 °W
No CTD (too cold and windy) — (ARGOS loc.)

Time: February 14, 1991 — Day 45, 1540GMT
Ice: 44, 47 and 48cm — Floe size 1x1 km
Snow: 8, 12 and 10cm — 9/10 ice conc.

Station 9107

Location: 20 miles east of Gannet Island — Lat. 53.998 °N
Small IMP beacon #1054 — Long. 56.024 °W
CTD Stn. File CWFEB020.DAT — (ARGOS loc.)

Time: February 14, 1991 — Day 45, 1430GMT
Ice: 51, 51 and 48cm — Floe size 1x1 km
Snow: 1, 1 and 1cm — 9/10 ice conc.

Sample#	Depth cm	Bottle #	Salinity ppt
9107.01	5 - 10	64630	15.920
9107.02	20 - 25	64631	10.373
9107.03	30 - 35	64632	12.645

Station 9108

Location: 15 miles east of Mary's Harbour — Lat. 52.442 °N
Large location beacon #3319 — Long. 55.033 °W
CTD Stn. File MARYS00.DAT — (ARGOS loc.)

Time: March 15, 1991 — Day 74, 1600GMT
Ice: 135, 130, 142 and 138cm — Floe size 30x40 m
Snow: 0, 0 and 0cm — 9/10 ice conc.

Sample#	Depth cm	Bottle #	Salinity ppt
9108.01	15 - 25	64654	6.855
9108.02	30 - 40	64653	10.706
9108.03w	55 - 55	64652	18.351
9108.04	75 - 85	64658	8.447

Station 9109 (Seal Herd)

Location: 10 miles east of Mary's Harbour — Lat. 52.390 °N
Large location beacon #3320 — Long. 55.238 °W
CTD Stn. File MARYS01.DAT — (ARGOS loc.)

Time: March 15, 1991 — Day 74, 1630GMT
Ice: 180, 190 and 184cm — Floe size 30x50 m
Snow: 4, 4 and 5cm (frozen snow) — 9/10 ice conc.

Sample#	Depth cm	Bottle #	Salinity ppt
9109.01	20 - 25	64657	8.032
9108.02	30 - 35	64656	12.610

Station 9110

Location: 5 miles east of Mary's Harbour — Lat. 52.378 °N
Small IMP beacon # 1053 — Long. 55.457 °W
CTD Stn. File MARYS02.DAT — (ARGOS loc.)

Time: March 15, 1991 — Day 74, 1730GMT
Ice: 86, 88 and 84cm — Floe size 60x90 m
Snow: 5, 4 and 4.5cm (frozen snow) — 9/10 ice conc.

Sample#	Depth cm	Bottle #	Salinity ppt
9110.01	0 - 5	64655	11.948
9110.02	20 - 25	64659	15.316
9110.03w	30 - 35	64660	11.852

Station 9111

Location: 50 miles east of Gannet Island — Lat. 54.498 °N
Large location beacon #8648 — Long. 56.123 °W
CTD Stn. File CART00.DAT and CART01.DAT — (ARGOS loc.)

Time: March 16, 1991 — Day 75, 1600GMT
Ice: 56, 48 and 52cm — Floe size 2x2 km
Snow: 8, 4, 5 and 10cm — 10/10 ice conc.

Sample#	Depth cm	Bottle #	Salinity ppt
9111.01	5 - 10	64637	14.445
9111.02w	20 - 25	64634	11.826
9108.03w	40 - 45	64640	12.384

Station 9112

Location: 35 miles east of Gannet Island — Lat. 54.338 °N
Small IMP beacon #1053 — Long. 56.422 °W
CTD Stn. File CART02.DAT — (ARGOS loc.)

Time: March 16, 1991 — Day 75, 1700GMT
Ice: 55, 50 and 52cm — Floe size 1.5x2 km
Snow: 6, 8 and 6cm (hard frozen snow) — 10/10 ice conc.

Sample#	Depth cm	Bottle #	Salinity ppt
9111.01	5 - 10	64641	8.490
9111.02	15 - 20	64633	9.036
9108.03w	25 - 30	64638	11.866

Station 9113

Location: 15 miles east of Gannet Island — Lat. 54.198 °N
Small location beacon #4762 — Long. 56.726 °W
CTD Stn. File CART03.DAT — (ARGOS loc.)

Time: March 16, 1991 — Day 75, 1800GMT
Ice: 62, 60, 59 and 62cm — Floe size 1.5x2 km
Snow: 3, 6 and 5cm — 9/10 ice conc.

Sample#	Depth cm	Bottle #	Salinity ppt
9113.01	10 - 15	64636	8.301
9113.02w	25 - 30	64635	13.707

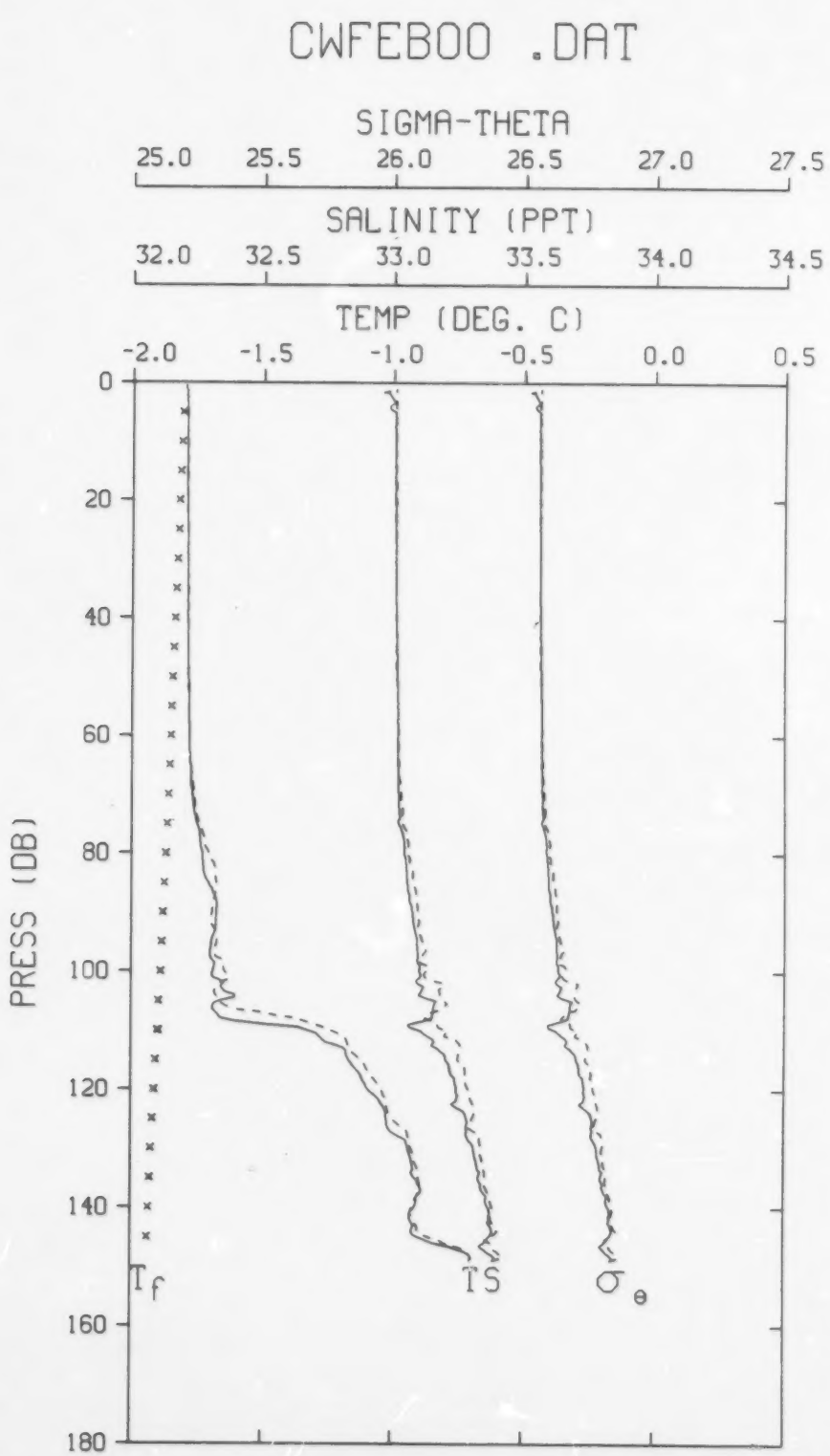
APPENDIX E: TEMPERATURE AND SALINITY DATA

Plots and listings of Seabird CTD data (pressure, temperature, salinity and density (σ_θ)). In the plots, T_f represents the freezing point at in situ pressure.

	Stn. #	Date	Site	Beacon #	File #
1.	9102	Feb. 12	outer	2376	cwfeb00
2.	9103	Feb. 12	middle	5437	cwfeb01
3.	9107	Feb. 14	inner	1054	cwfeb020
4.	9108	Mar. 15	outer	3319	marys00
5.	9109	Mar. 15	middle	3320	marys01
6.	9111	Mar. 16	outer	8648	cart00
7.	9112	Mar. 16	middle	1053	cart01
8.	9113	Mar. 16	inner	4762	cart02
9.	9113	Mar. 16	inner	4762	cart03

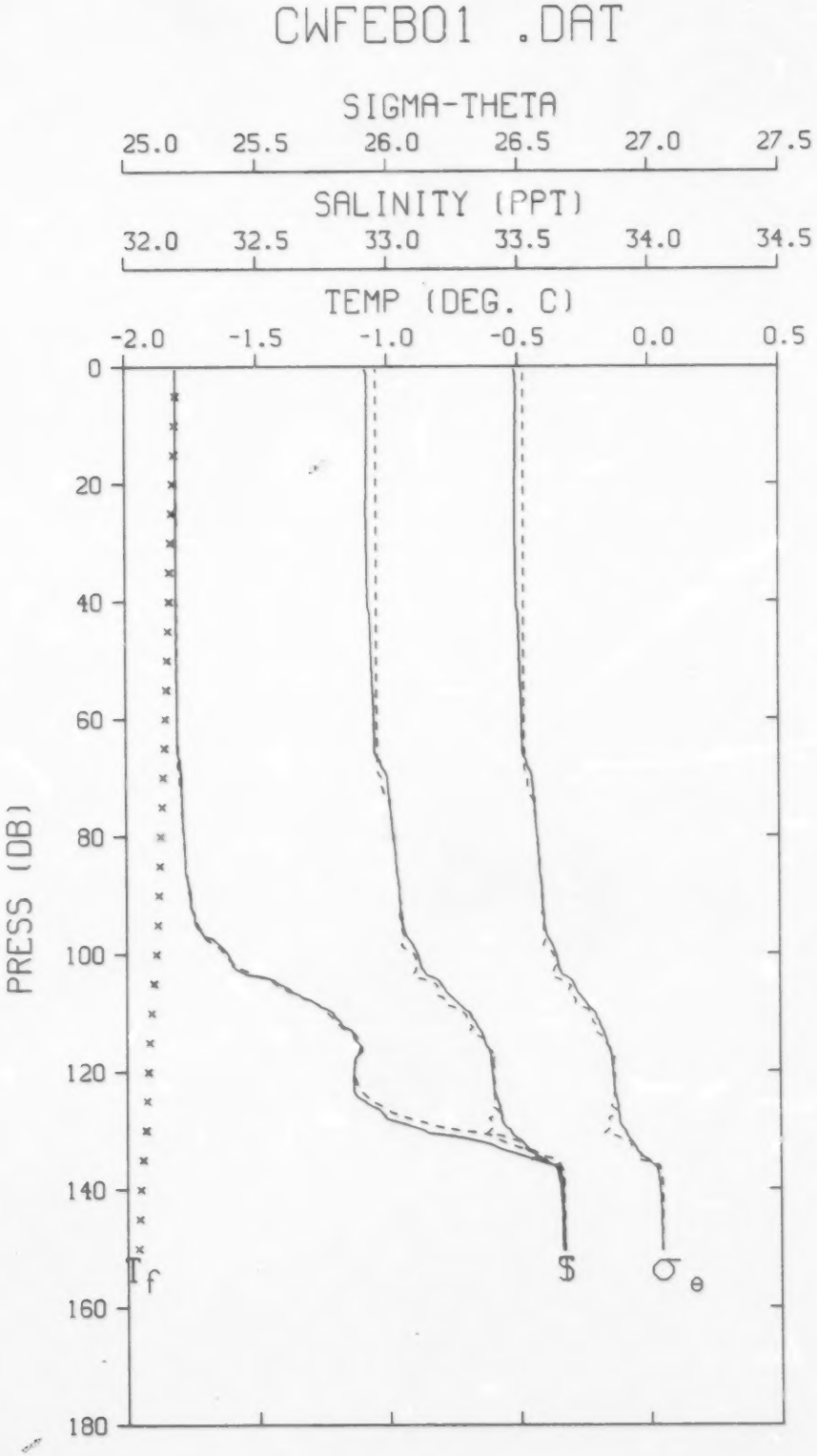
raw data file = cwfeb00.dat

dbars	temp	salinity	sigmatheta
5.	-1.7909	33.0085	26.5615
10.	-1.7906	33.0092	26.5621
15.	-1.7892	33.0094	26.5622
20.	-1.7891	33.0099	26.5626
25.	-1.7881	33.0097	26.5624
30.	-1.7873	33.0115	26.5638
35.	-1.7868	33.0112	26.5636
40.	-1.7866	33.0121	26.5643
45.	-1.7861	33.0128	26.5649
50.	-1.7855	33.0158	26.5673
55.	-1.7817	33.0204	26.5709
60.	-1.7807	33.0231	26.5731
65.	-1.7745	33.0253	26.5748
70.	-1.7635	33.0341	26.5817
75.	-1.7408	33.0404	26.5863
80.	-1.7048	33.0625	26.6034
85.	-1.6755	33.0826	26.6190
90.	-1.6921	33.1001	26.6337
95.	-1.6725	33.1168	26.6468
100.	-1.6428	33.1306	26.6573
105.	-1.6667	33.2010	26.7151
110.	-1.2386	33.2154	26.7149
115.	-1.1184	33.2524	26.7411
120.	-1.0375	33.2933	26.7715
125.	-0.9946	33.3081	26.78[illegible]
130.	-0.9240	33.3410	26.8063
135.	-0.8944	33.3585	26.8193
140.	-0.9201	33.3880	26.8442
145.	-0.8537	33.3745	26.8308


CWFEB00 .DAT
SIGMA-THETA
25.0
25.5
26.0
26.5
27.0
27.5
SALINITY (PPT)
32.0
32.5
33.0
33.5
34.0
34.5
TEMP (DEG. C)
-2.0
-1.5
-1.0
-0.5
0.0
0.5
PRESS (DB)
0
20
40
60
80
100
120
140
160
180
T_f
TS
θ

raw data file = cwfeb01.dat

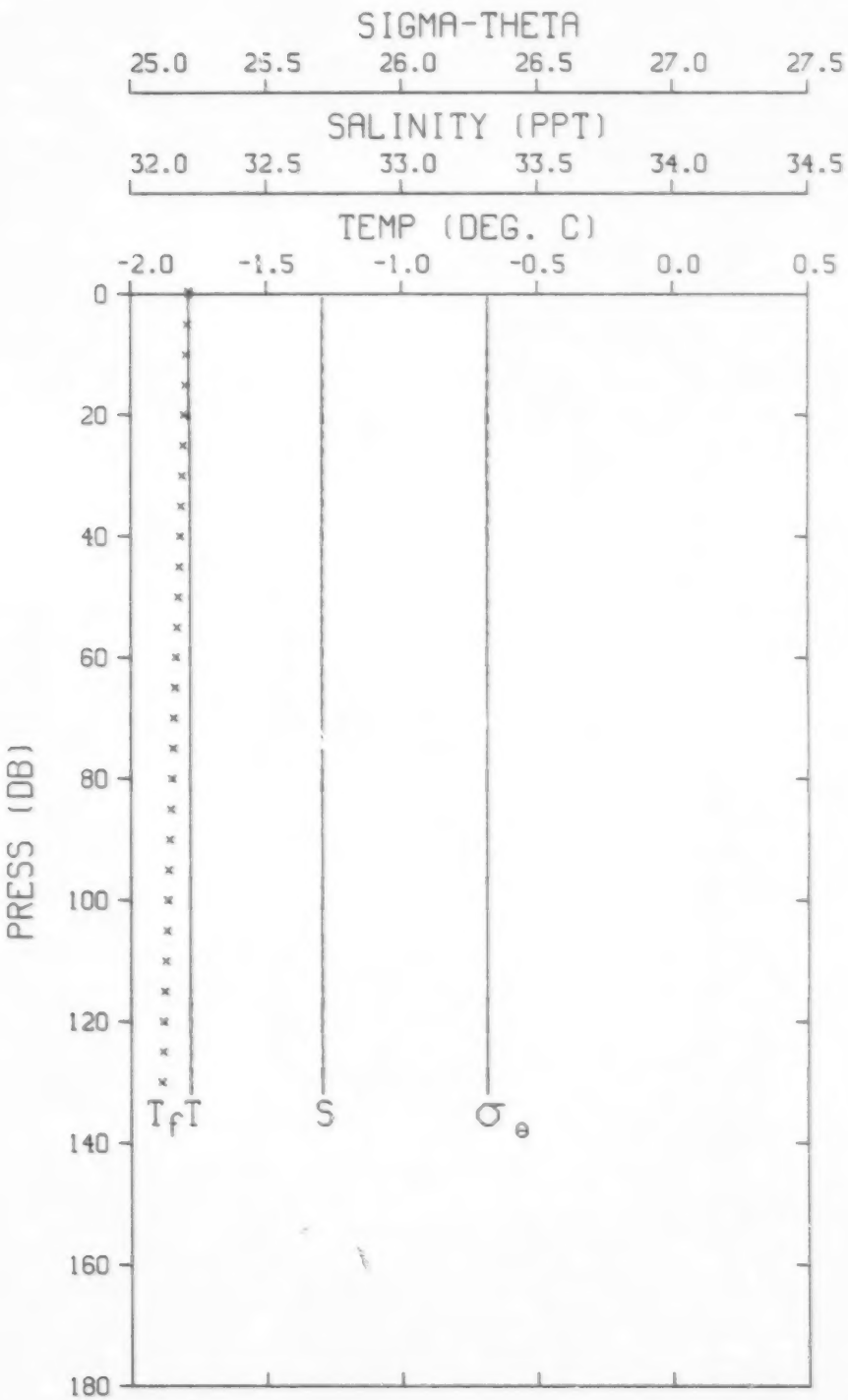
dbars	temp	salinity	sigmatheta
5.	-1.8035	32.9590	26.5215
10.	-1.8037	32.9589	26.5215
15.	-1.8034	32.9589	26.5214
20.	-1.8033	32.9588	26.5214
25.	-1.8032	32.9591	26.5216
30.	-1.8034	32.9585	26.5211
35.	-1.8034	32.9584	26.5211
40.	-1.8033	32.9581	26.5208
45.	-1.8033	32.9583	26.5210
50.	-1.8029	32.9582	26.5209
55.	-1.8028	32.9580	26.5207
60.	-1.8026	32.9592	26.5216
65.	-1.8014	32.9601	26.5224
70.	-1.7950	32.9765	26.5356
75.	-1.7861	33.0085	26.5614
80.	-1.7817	33.0199	26.5706
85.	-1.7729	33.0324	26.5805
90.	-1.7569	33.0418	26.5878
95.	-1.7297	33.0517	26.5952
100.	-1.6241	33.0974	26.6298
105.	-1.4364	33.1765	26.6891
110.	-1.2339	33.2853	26.7714
115.	-1.1152	33.3663	26.8333
120.	-1.1323	33.4025	26.8632
125.	-1.0600	33.4035	26.8616
130.	-0.7410	33.3905	26.8395
135.	-0.3615	33.5415	26.9460
140.	-0.3322	33.6681	27.0470
145.	-0.3299	33.6684	27.0472
150.	-0.3280	33.6679	27.0466


CWFEB01 .DAT
SIGMA-THETA
25.0
25.5
26.0
26.5
27.0
27.5
SALINITY (PPT)
32.0
32.5
33.0
33.5
34.0
34.5
TEMP (DEG. C)
-2.0
-1.5
-1.0
-0.5
0.0
0.5
PRESS (DB)
0
20
40
60
80
100
120
140
160
180
T_f
S
σ_θ

raw data file = cwfeb020.dat

dbars	temp	salinity	sigmatheta
0.	-1.7862	32.7087	26.3177
5.	-1.7854	32.7085	26.3175
10.	-1.7847	32.7085	26.3175
15.	-1.7847	32.7087	26.3176
20.	-1.7841	32.7088	26.3177
25.	-1.7833	32.7083	26.3173
30.	-1.7827	32.7084	26.3174
35.	-1.7825	32.7087	26.3176
40.	-1.7825	32.7084	26.3174
45.	-1.7822	32.7082	26.3172
50.	-1.7822	32.7082	26.3172
55.	-1.7822	32.7084	26.3174
60.	-1.7820	32.7082	26.3172
65.	-1.7820	32.7080	26.3170
70.	-1.7818	32.7076	26.3167
75.	-1.7819	32.7077	26.3168
80.	-1.7818	32.7077	26.3168
85.	-1.7815	32.7078	26.3168
90.	-1.7814	32.7072	26.3164
95.	-1.7812	32.7074	26.3165
100.	-1.7814	32.7074	26.3166
105.	-1.7808	32.7068	26.3160
110.	-1.7807	32.7070	26.3162
115.	-1.7806	32.7069	26.3161
120.	-1.7807	32.7070	26.3162
125.	-1.7806	32.7069	26.3162
130.	-1.7798	32.7064	26.3157

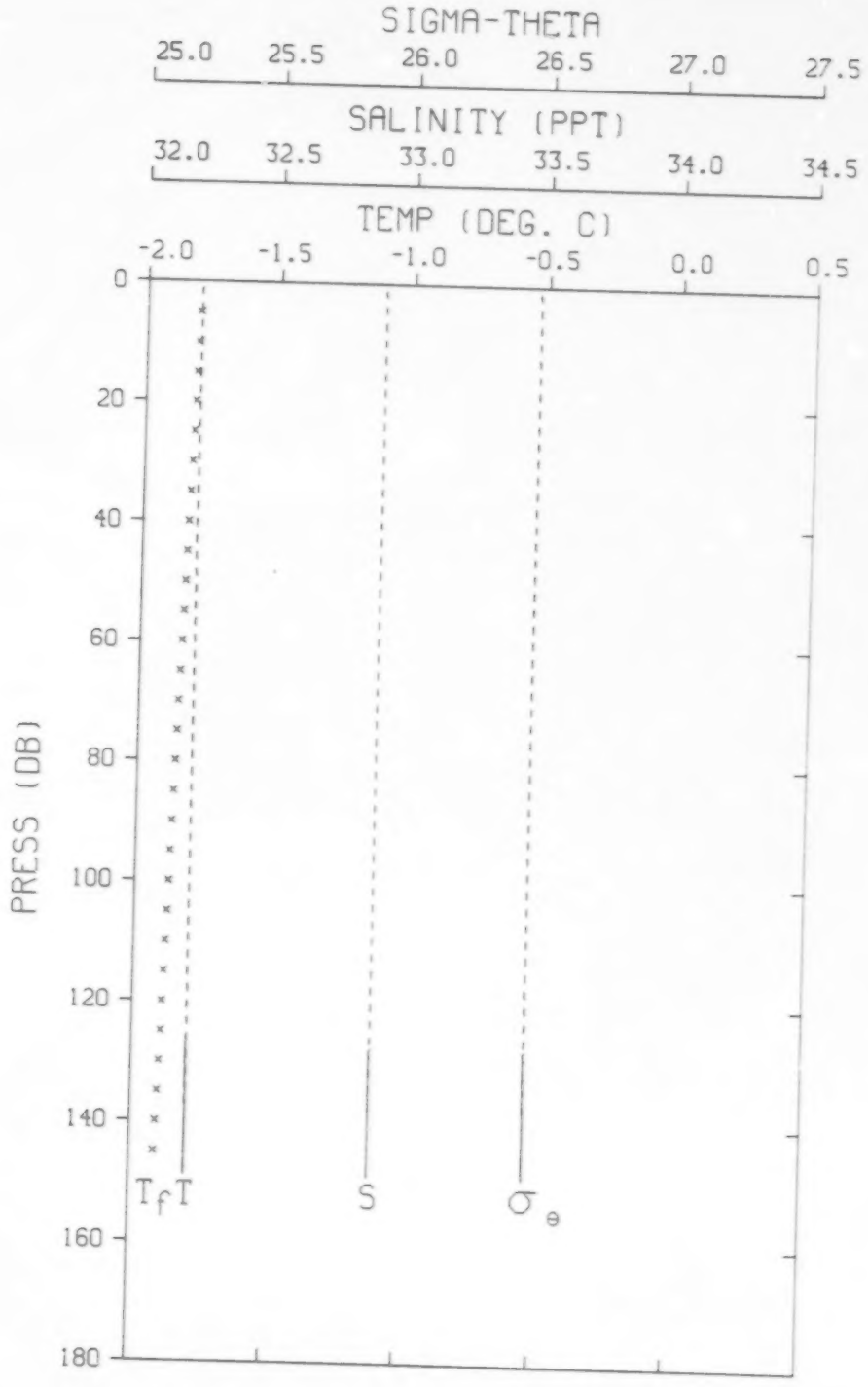
CWFEB020.DAT



raw data file = marys00.dat

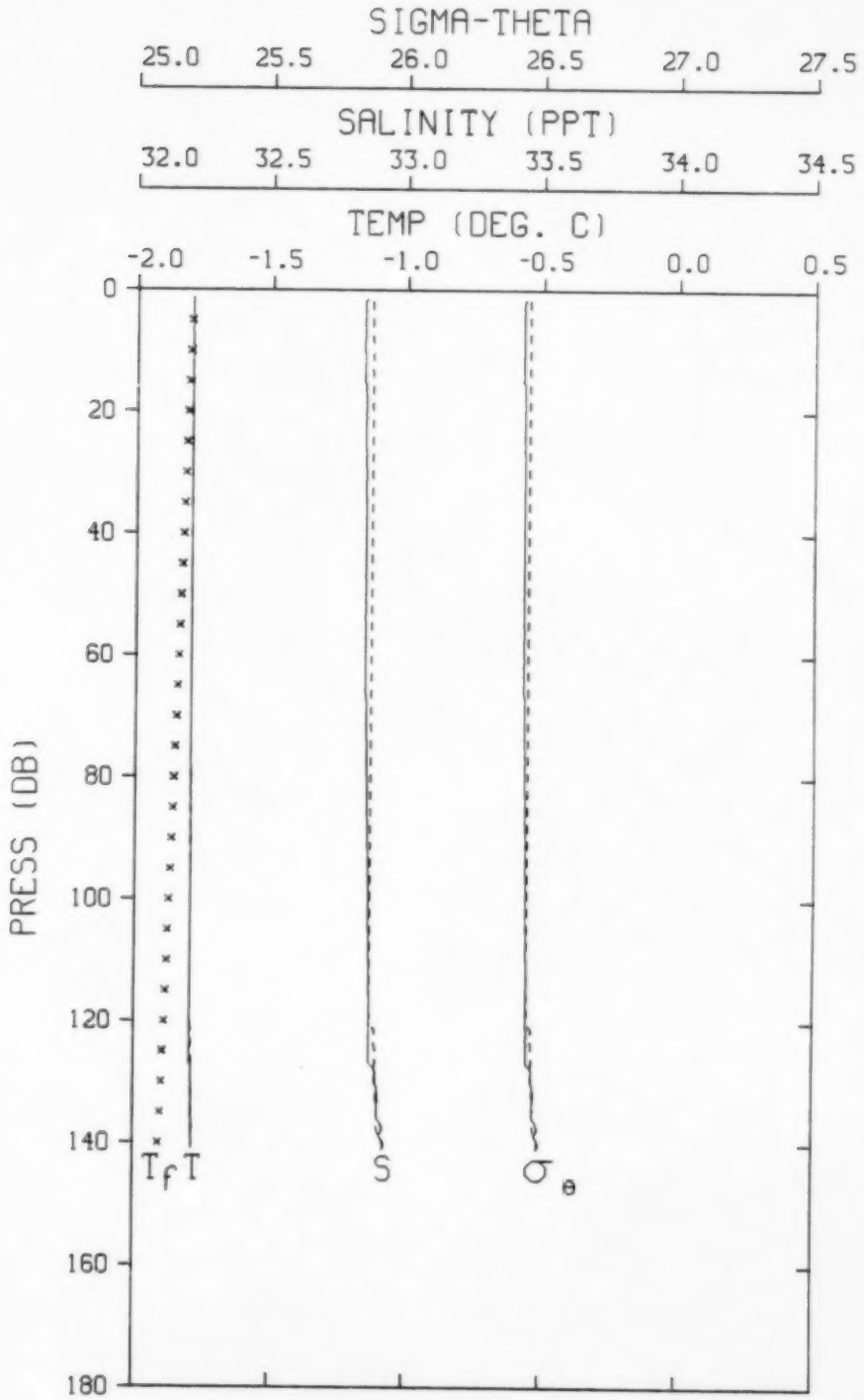
dbars	temp	salinity	sigmatheta
5.	-1.7981	32.8937	26.4683
10.	-1.7977	32.8939	26.4685
15.	-1.7979	32.8939	26.4685
20.	-1.7978	32.8944	26.4689
25.	-1.7980	32.8943	26.4688
30.	-1.7976	32.8939	26.4685
35.	-1.7976	32.8938	26.4684
40.	-1.7973	32.8938	26.4684
45.	-1.7971	32.8939	26.4684
50.	-1.7971	32.8939	26.4685
55.	-1.7969	32.8937	26.4683
60.	-1.7967	32.8936	26.4682
65.	-1.7966	32.8941	26.4686
70.	-1.7966	32.8942	26.4687
75.	-1.7964	32.8939	26.4685
80.	-1.7962	32.8936	26.4683
85.	-1.7961	32.8939	26.4685
90.	-1.7960	32.8937	26.4683
95.	-1.7958	32.8932	26.4679
100.	-1.7958	32.8936	26.4682
105.	-1.7956	32.8939	26.4685
110.	-1.7955	32.8939	26.4685
115.	-1.7954	32.8935	26.4681
120.	-1.7951	32.8935	26.4681
125.	-1.7949	32.8929	26.4677
130.	-1.7949	32.8934	26.4681
135.	-1.7942	32.8931	26.4678
140.	-1.7938	32.8941	26.4686
145.	-1.7942	32.8948	26.4692

MARYSOO .DAT


SIGMA-THETA
25.0
25.5
26.0
26.5
27.0
27.5
SALINITY (PPT)
32.0
32.5
33.0
33.5
34.0
34.5
TEMP (DEG. C)
-2.0
-1.5
-1.0
-0.5
0.0
0.5
PRESS (DB)
0
20
40
60
80
100
120
140
160
180
T_f T
S
σ_θ

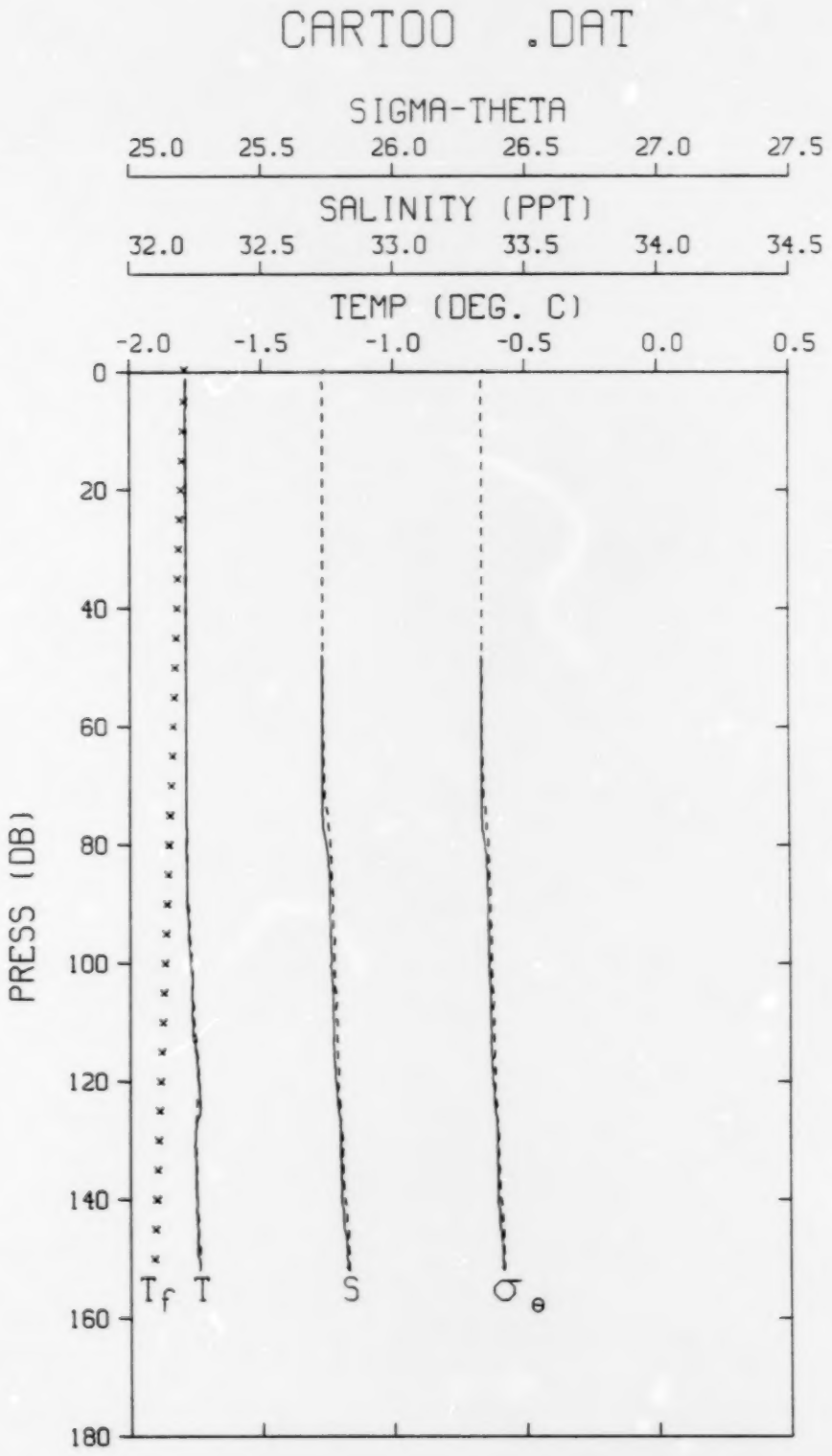
raw data file = marys01.dat

dbars	temp	salinity	sigmatheta
5.	-1.7968	32.8717	26.4504
10.	-1.7967	32.8723	26.4509
15.	-1.7967	32.8720	26.4507
20.	-1.7961	32.8720	26.4506
25.	-1.7964	32.8726	26.4512
30.	-1.7962	32.8726	26.4511
35.	-1.7963	32.8727	26.4512
40.	-1.7960	32.8725	26.4511
45.	-1.7960	32.8727	26.4512
50.	-1.7959	32.8727	26.4512
55.	-1.7956	32.8725	26.4510
60.	-1.7958	32.8727	26.4512
65.	-1.7956	32.8728	26.4513
70.	-1.7955	32.8724	26.4509
75.	-1.7955	32.8724	26.4509
80.	-1.7954	32.8724	26.4510
85.	-1.7953	32.8727	26.4512
90.	-1.7952	32.8728	26.4513
95.	-1.7950	32.8728	26.4513
100.	-1.7947	32.8722	26.4508
105.	-1.7947	32.8728	26.4513
110.	-1.7944	32.8726	26.4511
115.	-1.7938	32.8735	26.4519
120.	-1.7933	32.8786	26.4560
125.	-1.7890	32.8984	26.4720
130.	-1.7890	32.8962	26.4702
135.	-1.7865	32.9037	26.4762
140.	-1.7829	32.9256	26.4940


MARYS01 .DAT
SIGMA-THETA
25.0
25.5
26.0
26.5
27.0
27.5
SALINITY (PPT)
32.0
32.5
33.0
33.5
34.0
34.5
TEMP (DEG. C)
-2.0
-1.5
-1.0
-0.5
0.0
0.5
PRESS (DB)
0
20
40
60
80
100
120
140
160
180
T_f T
S
σ_θ

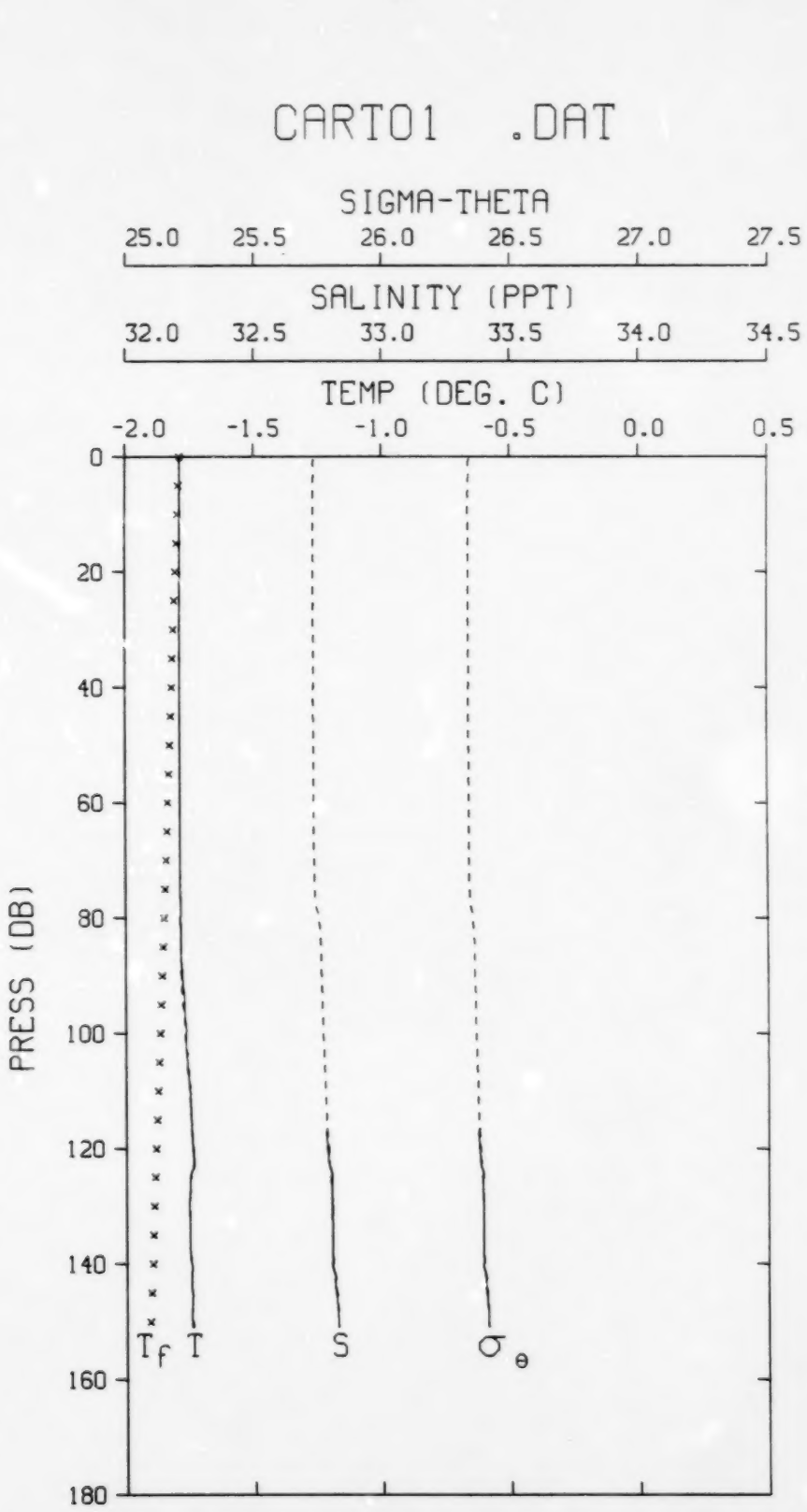
raw data file = cart00.dat

dbars	temp	salinity	sigmatheta
5.	-1.7875	32.7341	26.3384
10.	-1.7872	32.7342	26.3384
15.	-1.7872	32.7348	26.3389
20.	-1.7873	32.7352	26.3392
25.	-1.7871	32.7349	26.3389
30.	-1.7865	32.7354	26.3394
35.	-1.7871	32.7356	26.3396
40.	-1.7872	32.7359	26.3398
45.	-1.7870	32.7353	26.3393
50.	-1.7866	32.7350	26.3390
55.	-1.7867	32.7356	26.3395
60.	-1.7868	32.7361	26.3399
65.	-1.7866	32.7371	26.3408
70.	-1.7866	32.7415	26.3443
75.	-1.7853	32.7544	26.3548
80.	-1.7855	32.7633	26.3621
85.	-1.7841	32.7670	26.3650
90.	-1.7795	32.7710	26.3682
95.	-1.7743	32.7758	26.3720
100.	-1.7648	32.7766	26.3724
105.	-1.7649	32.7839	26.3784
110.	-1.7580	32.7888	26.3822
115.	-1.7468	32.7898	26.3828
120.	-1.7377	32.7922	26.3845
125.	-1.7474	32.7979	26.3894
130.	-1.7528	32.8064	26.3964
135.	-1.7491	32.8077	26.3974
140.	-1.7455	32.8164	26.4043
145.	-1.7425	32.8284	26.4141
150.	-1.7349	32.8312	26.4162


CARTOO .DAT
SIGMA-THETA
25.0 25.5 26.0 26.5 27.0 27.5
SALINITY (PPT)
32.0 32.5 33.0 33.5 34.0 34.5
TEMP (DEG. C)
-2.0 -1.5 -1.0 -0.5 0.0 0.5
PRESS (DB)
0 20 40 60 80 100 120 140 160 180
T_f T
S
σ_θ

raw data file = cart01.dat

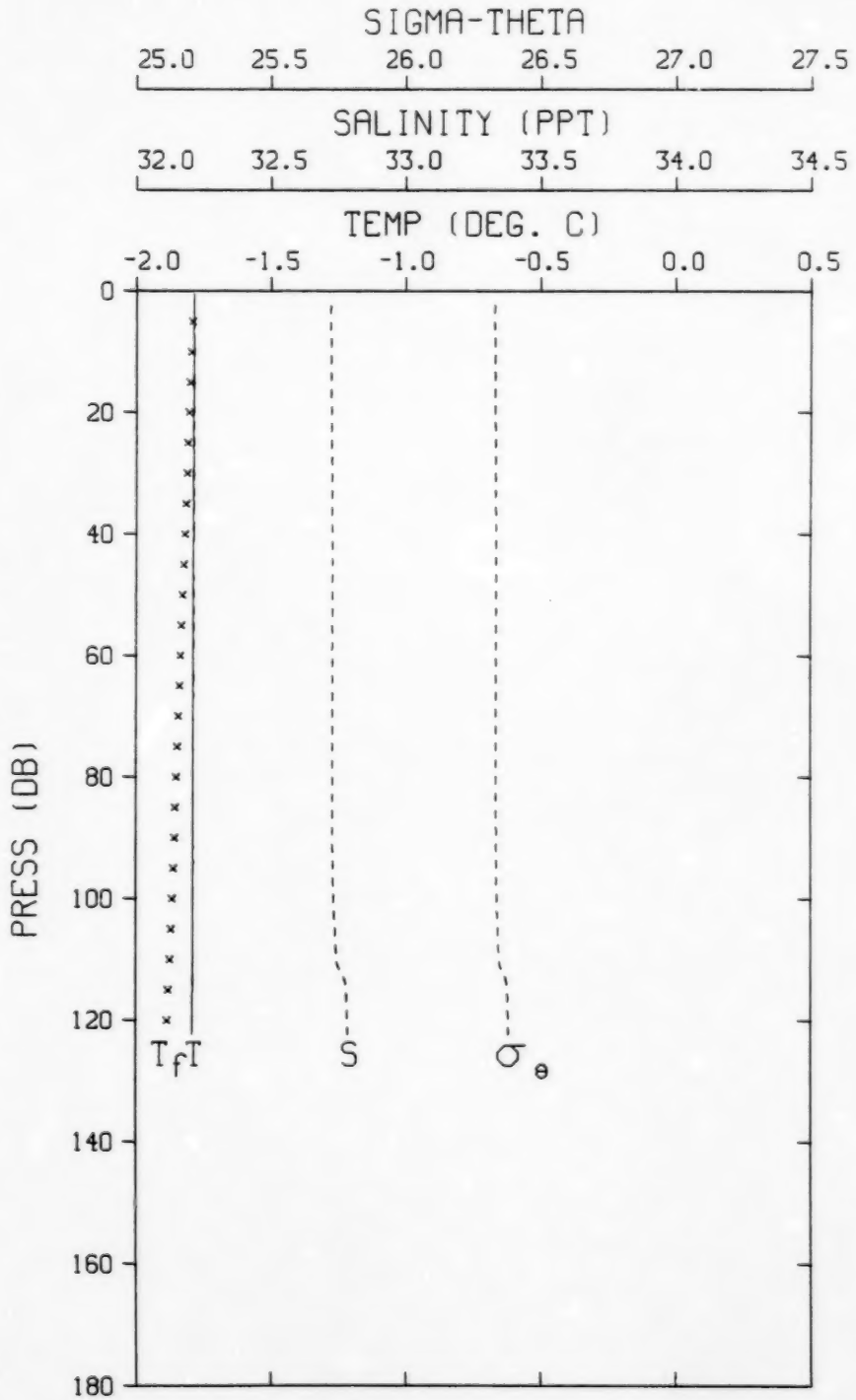
dbars	temp	salinity	sigmatheta
0.	-1.7945	32.7442	26.3467
5.	-1.7885	32.7355	26.3395
10.	-1.7885	32.7345	26.3387
15.	-1.7884	32.7356	26.3395
20.	-1.7885	32.7360	26.3399
25.	-1.7881	32.7358	26.3397
30.	-1.7883	32.7361	26.3400
35.	-1.7883	32.7365	26.3403
40.	-1.7882	32.7364	26.3402
45.	-1.7881	32.7361	26.3400
50.	-1.7882	32.7368	26.3406
55.	-1.7882	32.7370	26.3407
60.	-1.7878	32.7371	26.3408
65.	-1.7874	32.7376	26.3412
70.	-1.7874	32.7386	26.3420
75.	-1.7872	32.7393	26.3426
80.	-1.7866	32.7557	26.3559
85.	-1.7851	32.7641	26.3627
90.	-1.7844	32.7653	26.3636
95.	-1.7788	32.7682	26.3659
100.	-1.7707	32.7712	26.3681
105.	-1.7642	32.7760	26.3719
110.	-1.7524	32.7802	26.3751
115.	-1.7489	32.7835	26.3777
120.	-1.7426	32.7904	26.3832
125.	-1.7499	32.7993	26.3906
130.	-1.7559	32.8022	26.3930
135.	-1.7543	32.8041	26.3946
140.	-1.7480	32.8060	26.3960
145.	-1.7449	32.8215	26.4085
150.	-1.7440	32.8270	26.4130


CARTO1 .DAT
SIGMA-THETA
25.0 25.5 26.0 26.5 27.0 27.5
SALINITY (PPT)
32.0 32.5 33.0 33.5 34.0 34.5
TEMP (DEG. C)
-2.0 -1.5 -1.0 -0.5 0.0 0.5
PRESS (DB)
0 20 40 60 80 100 120 140 160 180
T_f T
S
σ_θ

raw data file = cart02.dat

dbars	temp	salinity	sigmatheta
5.	-1.7856	32.7227	26.3290
10.	-1.7858	32.7237	26.3298
15.	-1.7861	32.7249	26.3308
20.	-1.7863	32.7262	26.3319
25.	-1.7863	32.7268	26.3324
30.	-1.7868	32.7281	26.3335
35.	-1.7864	32.7287	26.3339
40.	-1.7871	32.7299	26.3349
45.	-1.7871	32.7305	26.3355
50.	-1.7867	32.7303	26.3352
55.	-1.7865	32.7302	26.3352
60.	-1.7870	32.7301	26.3351
65.	-1.7869	32.7306	26.3355
70.	-1.7873	32.7305	26.3354
75.	-1.7874	32.7306	26.3355
80.	-1.7874	32.7309	26.3358
85.	-1.7871	32.7309	26.3358
90.	-1.7872	32.7316	26.3363
95.	-1.7873	32.7329	26.3374
100.	-1.7875	32.7354	26.3394
105.	-1.7882	32.7410	26.3440
110.	-1.7888	32.7478	26.3496
115.	-1.7898	32.7811	26.3766
120.	-1.7900	32.7858	26.3805

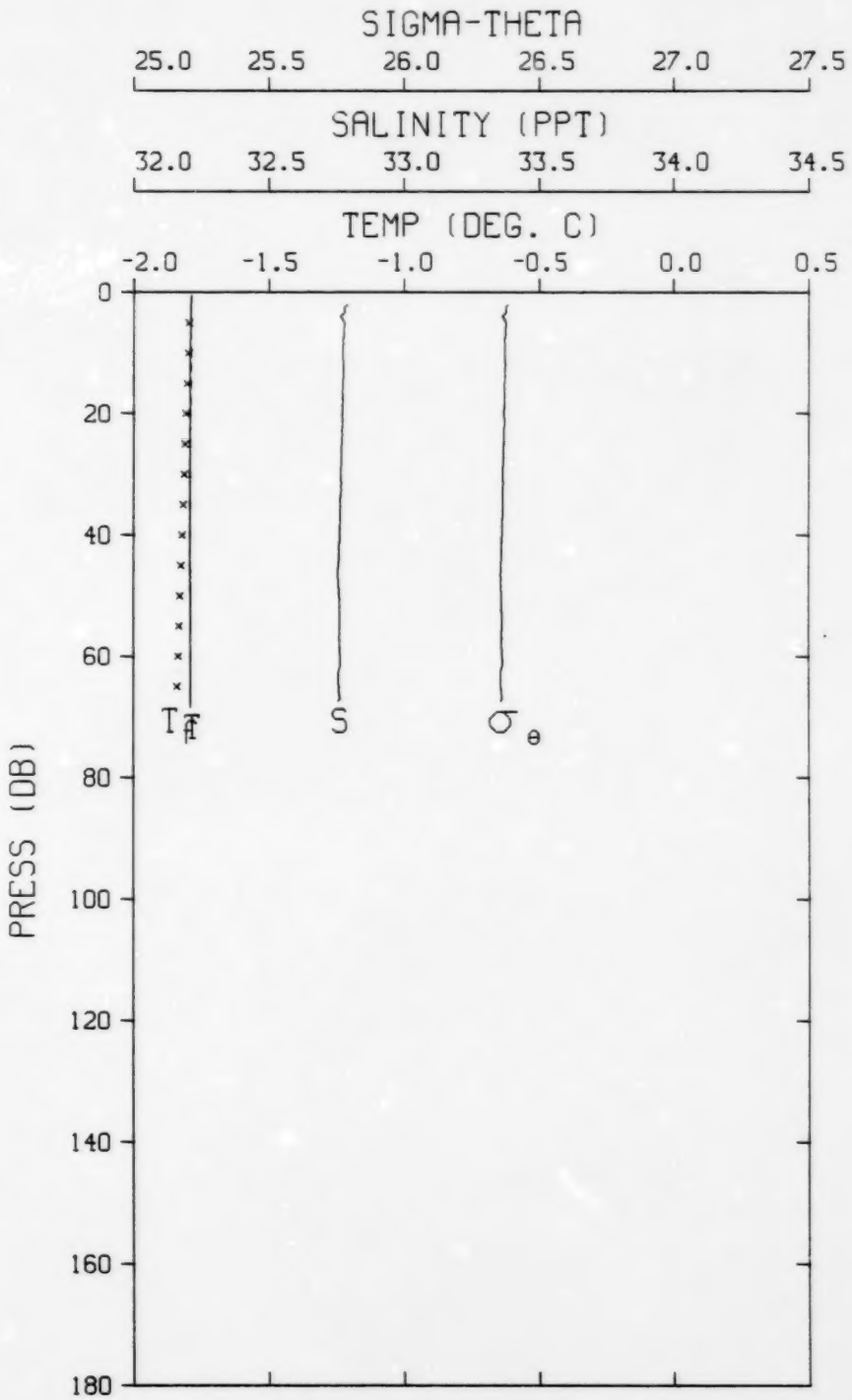
CARTO2 .DAT


SIGMA-THETA
25.0
25.5
26.0
26.5
27.0
27.5
SALINITY (PPT)
32.0
32.5
33.0
33.5
34.0
34.5
TEMP (DEG. C)
-2.0
-1.5
-1.0
-0.5
0.0
0.5
PRESS (DB)
0
20
40
60
80
100
120
140
160
180
T
T_f
S
σ_θ

raw data file = cart03.dat

dbars	temp	salinity	sigmatheta
5.	-1.7906	32.7783	26.3743
10.	-1.7916	32.7734	26.3704
15.	-1.7915	32.7730	26.3700
20.	-1.7918	32.7699	26.3675
25.	-1.7913	32.7682	26.3661
30.	-1.7915	32.7638	26.3626
35.	-1.7916	32.7626	26.3616
40.	-1.7915	32.7601	26.3596
45.	-1.7911	32.7552	26.3556
50.	-1.7907	32.7588	26.3585
55.	-1.7906	32.7613	26.3605
60.	-1.7902	32.7614	26.3606
65.	-1.7902	32.7572	26.3572

CARTO3 .DAT


SIGMA-THETA
25.0
25.5
26.0
26.5
27.0
27.5
SALINITY (PPT)
32.0
32.5
33.0
33.5
34.0
34.5
TEMP (DEG. C)
-2.0
-1.5
-1.0
-0.5
0.0
0.5
PRESS (DB)
0
20
40
60
80
100
120
140
160
180
T
S
σθ

APPENDIX F: REFRACTOMETER-AUTOSALOMETER COMPARISON

ICE ANd WATER SALINITY (PPT) SAMPLES FROM THE LABRADOR SHELF SURVEY OF THE WINTER OF 1991

#	SAMPLE #	REFRACT.	AUTOSAL.	DIFF.
1	64633	8.5	9.04	-.45
2	64634	11.5	11.83	-.33
3	64635	13.0	13.71	-.71
4	64636	7.5	8.30	-.80
5	64637	14.0	14.45	-.45
6	64638	11.5	11.87	-.37
7	64639	12.0	12.75	-.75
8	64640	11.5	12.38	-.88
9	64641	8.0	8.49	-.49
10	64652	18.0	18.35	-.35
11	64653	10.5	10.70	-.20
12	64654	6.5	6.86	-.36
13	64655	12.0	11.95	+.05
14	64656	12.0	12.61	-.61
15	64657	8.0	8.03	-.03
16	64658	8.0	8.49	-.49
17	64659	15.0	15.32	-.32
18	64660	11.5	11.85	-.35
19	64661	29.0	29.33	-.33
20	73533	1.0	1.27	-.27
21	73534	0.0	0.34	-.34
22	73535	0.0	0.64	-.64
23	73538	0.0	1.05	-1.05
24	73542	0.5	1.23	-.73
25	73536	22.0	23.15	-1.15
			Mean*	-.50

*Another set of 29 ice and water samples from the Beaufort Sea had a similar offset of -.57 indicating that the refractometer readings are consistantly low by 0.5 ppt and should be adjusted by that amount.